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ON THE DESIGN OF PASSIVE RETRO-REFLECTORS FOR USE WITH PRECISE RADAR NAVIGATION SYSTEMS

by

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The contents of this report reflect the views of the contractor and not necessarily the official views or policies of the Transportation Development Centre.

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17. Abstract

A series of experiments, intended to study problems associated with the acquisition and tracking of land-based retro-reflectors by shipborne radar, as a prerequisite to the design of a precise radar navigation system (PRANS) for use on vessels operating in the St. Lawrence Seaway, is described.

A bistatic radar was used to illuminate, in succession, a number of dihedral and trihedral retro-reflectors, mounted on a tower, 2200 metres from the radar. Returns from the environment and from the various reflectors were recorded as a function of receiving antenna polarization. Vertical interference patterns were obtained by noting the returns from individual reflectors and from reflector constellations as a function of height above the water surface. It was concluded from the experiments that polarization diversity and space diversity, respectively, offer the basis for solutions to the clutter and multipath problems encountered during the evaluation of an existing PRANS. A number of recommendations are made concerning the development of a retro-reflector with broad azimuthal response, capable of generating a cross polarized return; the use of a dual polarized, monostatic radar in future experiments; and the investigation of certain aspects of the proposed system such as accuracy, reliability, tracking strategy and display methodology.

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17 Résumé

La conception d'un système de radionavigation de précision (système PRANS) à l'intention des bateaux empruntant la Voie maritime du Saint-Laurent est retardée à cause de problèmes d'acquisition et de poursuite des réflecteurs passif à terre par le radar de bord. Ce rapport décrit les expérimentations menées dans le but l'élucider ces problèmes.

Un radar à deux antennes a d'abord été utilisé pour éclairer, tour à tour, un certain nombre de réflecteurs passifs dièdres et trièdres montés sur pylônes distants de 2200 mètres du radar. Les échos renvoyés par le milieu environnant et les divers réflecteurs ont été enregistrés pour divers types de polarisation de l'antenne réceptrice. Les chercheurs ont dégagé les figures d'interference verticale en comparant les signaux réfléchis par des réflecteurs distincts et ceux obtenus de groupements de réflecteurs, en function de leur hauteur par rapport à la surface de l'eau. Les résultats indiquent que la solution des problèmes de clutter et de réflexions multiples, notés lors de l'évaluation d'un système PRANS existant, devrait être apportée par les techniques diversité, diversité de polarisation dans le premier cas et diversité d'emplacement dans le second. Le rapport présente un certain nombre de recommandations concernant la mise au point d'un reflecteur passif affichant une bonne réponse en azimut et capable de générer un signal de retour à polarisation croisée: l'utilisation d'un radar classique à antenne unique mais à double polarisation lors des expérimentations à venir; l'étude de certaines caractéristiques particulières du système envisagé, notamment sa précision et sa fiabilité, ainsi que les techniques de poursuite de la cible et de visualisation à mettre en oeuvre.

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Ed Lewis was instrumental in arranging for the use of the roof top radar facility at the Canada Center for Inland Waters (CCIW) and in obtaining the necessary radar equipment. Jerry Cavanaugh installed and maintained the Decca radar systems. Dave Pyatt modified the radar transponder used to align the antennas. Mike Powell surveyed the locations of the antenna pedestals and reflectors. Gunther Morwald assisted in the selection of a reflector site at Dofasco and acted as the liaison between CRL personnel and Dofasco. Harold Howell and Jerry DeBoer were responsible for constructing the antenna pedestals used at CCIW, the reflector mounting hardware installed at Dofasco and the dihedral reflectors. Jonathan Betz designed and built the interface between the RCA video recorder and the Decca transceivers. Jonathan also spent many hours at the Dofasco site in sub-zero weather positioning the reflectors, as required, during the experiments. Dr. H.C. Chan and Gaetan Danis served as technical advisors to the project officer and made a number of useful suggestions with regard to experimental procedures.

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SUMMARY

This report describes a series of experiments intended to study the problems associated with the acquisition and tracking of land-based retro-reflectors by shipborne radar as a pre-requisite to the design of an automatic navigation system for use on vessels operating in the St. Lawrence Seaway. The study originated as a result of an evaluation, during the summer and fall of 1980, of a precise radar navigation system (PRANS) manufactured by Associated Controls and Communications Incorporated (ACCI) of Salem, Massachusetts [1,2,3].

The primary objectives of the study were

- to investigate polarization diversity as a means for improving the visibility of retro-reflectors in high clutter environments, and

- to assess the impact of retro-reflector constellations on the vertical interference pattern that is both characteristic of multipath propagation and indicative of the signal fade experienced by the radar on a vessel approaching a retro-reflector.

To achieve these objectives, a bistatic radar system was installed on the roof of CCIW in Burlington and used to illuminate, in succession, a number of dihedral and trihedral reflectors mounted on a tower at Dofasco, approximately 2200 meters from the radar. Returns from the environment and from the various reflectors were studied as a function of polarization by rotating one of the receiving antennas about an axis coincident with line-of-sight to the retro-reflectors. Vertical interference patterns were obtained by observing the returns from individual reflectors and reflector constellations as a function of their height above the water surface.

It was concluded from the results of the experiments that

- the cross polarized return from a typical environment is less than the like polarized return, and, while both increase in the presence of precipitation, the former is affected to a lesser degree than the latter;

- the cross polarized return from a suitably oriented dihedral is distinct from the ambient clutter where the horizontally polarized return from a trihedral of comparable radar cross section is not;

- individual reflectors produce vertical interference patterns with pronounced nulls, as expected, while reflector constellations yield patterns without significant nulls; and

- interference from nearby marine radars is sufficient to disrupt retro-reflector acquisition and tracking in automatic navigation systems.

In view of the conclusions reached during the study, it is recommended that

- a monostatic radar with a dual polarized antenna be used in future experiments;

- the interference problem be resolved through the use of frequency diversity or coded transmissions;

- a retro-reflector with a broad azimuthal response and capable of generating a cross polarized return be developed;

- the retro-directive array be investigated as a means for producing the desired cross polarized response;

- additional polarization and multipath experiments be conducted;

- the accuracy and reliability of PRANS be re-evaluated using a dual polarized radar;

- a realistic set of cost-performance criteria be established for the proposed navigation system by interviewing potential users;

- potential tracking algorithms such as the Kalman filter be tested by computer simulation; and

- effective methods for displaying course and position information be devised.

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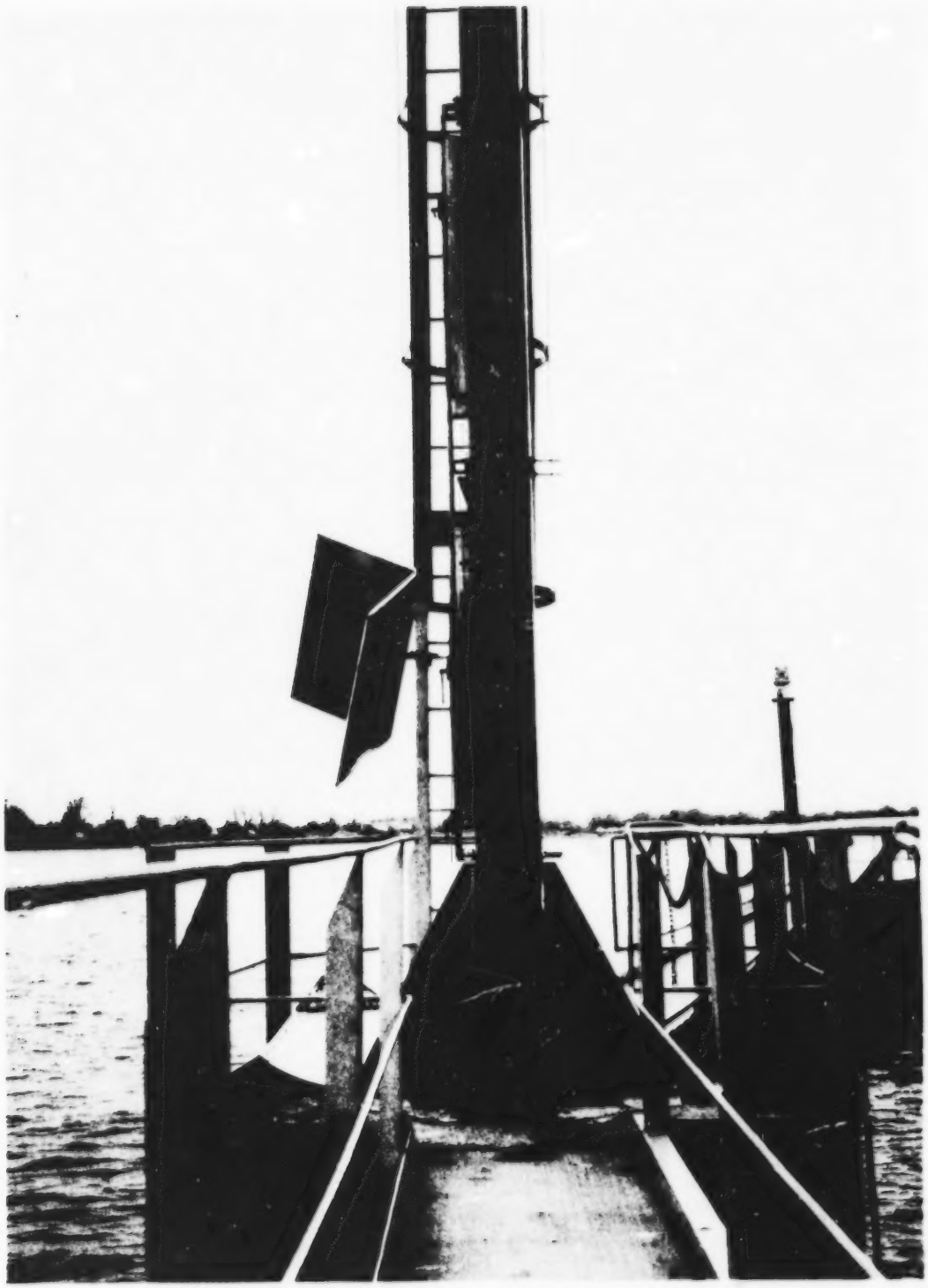


Dihedral Retro-reflector

1. INTRODUCTION

1.1 Background

The operation of commercial vessels in confined waterways, notably the St. Lawrence Seaway, is subject to a variety of constraints. Frequent and sometimes prolonged interruptions in vessel traffic are known to occur at the beginning of the season before floating navigation aids are in place, during the season in the event of fog or heavy precipitation, and at the end of the season when the aids have been withdrawn for winter storage. To increase traffic in the Seaway and extend the shipping season a reliable, all-weather navigation system, capable of establishing a vessel's position to within three metres, without relying on floating aids, is required to replace existing sytems which have proven inadequate.

In 1977, the Dominion Marine Association (DMA) was approached by Associated Controls and Communications Inc. (ACCI) in Salem, Massachusetts, with a proposal to evaluate a precise radar navigation system (PRANS) which was alleged to provide assistance in docking manoeuvres and allow automatic navigation to within three metres of a predetermined course. The system outlined in the proposal consisted of a minicomputer which calculated the ship's position relative to the desired course based on a series of range measurements to a number of shore-based, passive retro-reflectors in known locations, obtained with the aid of the ship's radar. Continuous navigation was realized by automatically switching between successive sets of retro-reflectors stationed along the waterway.

In September 1978, the Dominion Marine Association entered into an agreement with the Transporation Development Centre (TDC) which provided for testing of the ACCI system on a stretch of the St. Lawrence Seaway near Prescott, Ontario. A series of trials and demonstrations was conducted during the summer and fall of 1980 aboard a motor yacht owned by Upper Lakes Shipping Limited. The tests indicated that although PRANS showed some promise, a number of problems would have to be resolved before the system could be declared operational [1,2,3]. In particular, PRANS performed satisfactorily in static tests, but proved unreliable during dynamic tests due to frequent loss of signal. Failure to acquire or maintain adequate signal strength and inconsistencies in performance were attributed to spurious signals from targets other than the retro-reflectors (clutter) and to multipath induced fading. System performance was improved in the presence of clutter and multipath by resorting to larger retro-reflectors and to constellations of retro-reflectors both serving to increase the effective radar cross section and introduce space diversity. The problem of retro-reflector acquisition and tracking was deemed fundamental to the successful operation of the system and the solution was presumed to lie in the area of retro-reflector design.

1.2 Objectives

The original ACCI PRANS frequently had difficulty both recognizing and tracking retro-reflectors in a reliable manner on account of clutter and multipath. In the present study these are treated as separate and distinct problems.

Assuming extensive modifications to the radar transmitter are not permitted, there remain a number of alternatives for dealing with clutter. The most direct is to increase the effective radar cross section of the reflector until it overpowers the ambient clutter, however, this is seldom practical as physically large apertures are required particularly for low resolution radars. A second alternative involves changing the frequency of the target return so that it is easily distinguished from the clutter. A small change in frequency is produced by target motion while a significant change requires a receiver/transmitter combination as found in most radar transponders. Both solutions can be classified as "active" rather than "passive" and are consequently of little immediate interest. A third alternative is to adjust the polarization of the target return so that it differs substantially from that of the cluuter return. In support of this approach, an experiment conducted on the Borden peninsula of Baffin Island in the spring of 1981 revealed that the cross (vertically) polarized return from landfast sea ice is significantly weaker than the like (horizontally) polarized return [4,5]. Viewing the retro-reflector as a co-operative target, a gain in signal-to-clutter ratio would result if the reflector produced a cross polarized return since it would be competing with an inherently lower clutter return than on like polarization. This strategy is pursued in the present study.

To combat multipath induced fading there is but one viable technique namely, space diversity, in which the target is extended in the vertical dimension so that it no longer appears as a point source in relation to the vertical interference pattern characteristic of multipath [6]. The extension may be continuous as in a larger aperture or discrete as in the vertical replication of the original aperture giving rise to a constellation. Space diversity is a well recognized method for overcoming multipath particularly in the surface based line-of-sight microwave relay systems used in telecommunications.

In view of the preceding discussion, the immediate objectives of the study are as follows:

- to establish that the cross polarized return from an environment typical of the St. Lawrence Seaway is indeed significantly less than the like polarized return as observed in the case of landfast sea ice.

- to investigate the cross polarized return from common retro-reflectors such as the trihedral or corner reflector.

- to demonstrate the relative ease with which the cross polarized return produced by a suitably oriented dihedral can be distinguished from the clutter generated by its surroundings.

- to study the effects of precipitation on the polarization of the return and in particular on the cross polarized clutter return.

- to characterize the vertical interference pattern asociated with common retro-reflectors of modest aperture such as the dihedral and trihedral.

- to assess the impact of reflector constellations on the vertical interference pattern. The nulls of the pattern are expected to diminish

as the vertical extent of the constellation increases. Ultimately, a constellation which exhibits little fade as it is approached would be desireable.

- to determine the interaction between surface roughness and the vertical interference pattern, that is, does the depth of the nulls decrease with increasing surface roughness or since most multipath models assume specular reflection from the surface, does the introduction of surface roughness alter the degree of fade experienced?

1.3 Approach

In order to study polarization related phenomena a horizontally polarized X-band marine radar was used to illuminate in succession a number of common retro-reflectors including examples of both dihedral and trihedral designs. The reflectors were mounted on a tower of substantial cross section adjacent to a body of water with a clear field of view in the direction of the transceiver installation. The backdrop was a typical industrial setting comprising a mixture of buildings, piles of raw materials and vehicular traffic. It was considered to be a rather "hostile" environment in comparison to typical retro-reflector sites along the St. Lawrence Seaway and provided appreciable clutter when viewed on the radar plan position indicator (PPI) display, sufficient to mask the response from a large trihedral of the type employed by ACCI during the PRANS trials.

A bistatic antenna/receiver system was employed to study the returns from the various reflectors. One receiver was co-located with the transmitter, sharing the transmit antenna in the usual manner. It yielded the horizontally polarized return which served both as a control during the experiments and as a means for detecting fluctuations in the performance of the transmitter. A second receiver was coupled to an identical antenna mounted on a separate pedestal adjacent to the transmit pedestal. This antenna was rotated about an axis coincident with the line-of-sight to the retro-reflectors by means of a remotely controlled dual axis antenna positioner. Given that both antennas could be considered linearly polarized to a first approximation, this permitted the reflector responses to be viewed as a function of polarization over the entire range between horizontal and vertical polarization.

Essentially the same apparatus was used in studying the multipath problem, however, the antenna mounted on the positioner was oriented so as to receive either horizontal or vertical polarization depending upon the nature of the experiment. The vertical interference pattern, which is indicative of the signal fade experienced by a vessel approaching a retro-reflector, was obtained by observing the returns from individual dihedral and trihedral reflectors as a function of height above the water surface. The procedure was repeated for a pair of dihedral reflectors separated by one and one half times the distance between successive nulls in the interference pattern produced by a single dihedral. In effect, when one of the dihedrals coincided with a null, the other coincided with a maximum. For this reason, the interference pattern for the constellation was not expected to exhibit the pronounced nulls characteristic of that for a single dihedral.

In all experiments, the video outputs of both receivers were recorded simultaneously and later digitized to produce plots resembling the A-scope presentation normally seen on an oscilloscope. In preparing the plots, samples arising from consecutive transmissions were averaged to eliminate the fluctuations introduced by thermal noise, which tended to obscure the phenomena under observation.

The polarization and multipath experiments were performed independently in the sense that no attempt was made to study multipath as a function of polarization other than at like and cross polarization. Further, due to limitations imposed by the positioner, the experiments were conducted with the antennas dwelling on the retro-reflectors rather than scanning in azimuth which is the customary mode of operation.

2. DATA COLLECTION

2.1 Site Description

The experiments were conducted at various locations around Hamilton Harbour between December 1982 and March 1983. The sites were all within easy reach of McMaster University permitting equipment and personnel to be moved about as required. Fortunately, the harbour remained free of ice throughout the study due to unseasonably mild weather.

The transmitters, receivers and antennas were situated on the roof of the Canada Centre for Inland Waters (CCIW) in Burlington approximately 35 metres above the surface of the harbour. The antennas and pedestals were exposed to the weather while the remaining equipment shared the penthouse enclosure with numerous ducts and ventilating fans.

The retro-reflectors were mounted near the base of a 10 metre steel tower situated on the waterfront adjacent to a loading dock belonging to the Dominion Foundries and Steel Company (Dofasco) approximately 2200 metres from the radar installation at CCIW. The tower is located 10 metres from the shore on a concrete platform with access from the mainland via a series of interconnecting catwalks. The tower was originally built to house atmospheric pollution monitoring equipment but was vacant at the time of the study. Thirty metre steel lamp standards are stationed at either end of the loading dock, the nearer of the two falling within the beamwidth of the vertically polarized antenna and contributing to the ambient clutter return. On shore, immediately behind the tower, is a roadway that is frequently travelled by vehicles of various sizes including a hot slag carrier. Across the roadway is a holding area for bulk materials, the piles changing size, shape and location on a daily basis as their contents are consumed. In the distance are the blast furnaces and rolling mills that comprise the foundry.

A plan view of Hamilton Harbour is presented in Figure 1, an expanded view showing the CCIW-Dofasco corridor, in Figure 2 and a profile of the test site, illustrating the range geometry, in Figure 3.

2.2 Radar Facility

In order to interrogate the retro-reflectors situated across the harbour at Dofasco a bistatic radar sytem was assembled on the roof of the Canada Centre for Inland Waters in Burlington from components supplied by CCIW and by the Ocean Sciences and Surveys Branch (OSS) of the Department of Fisheries and Oceans (DFO). The facility consisted of a pair of two metre, slotted array antennas along with the requisite transceivers, rectifiers and plan position indicators (PPI). A diagram illustrating the relationship between the various components is presented in Figure 4. The individual components are identified in Table 1.

The antenna pedestals, shown in Figures 5 and 6, performed separate functions and possessed different characteristics though the same scanning unit (antenna) was used in both instances. The transmit-receive pedestal, consisting of a Decca turning unit and scanner, provided horizontally polarized illumination of the retro-reflectors and permitted the horizontally polarized response to be monitored at all times. A riflescope was mounted beneath the scanning unit, as shown in Figure 7, to ensure proper alignment with the retro-reflectors. The receive-only pedestal, consisting of a remotely controlled Scientific Atlanta antenna positioner and a scanner identical to that used on the transmit-receive pedestal, permitted the response of a retro-reflector to be viewed as a function of polarization by providing for rotation of the scanner about an axis coincident with line-of-sight to the reflector. The pedestals were connected, via lengths of WR90 waveguide, to separate Decca transceiver units located in a small room at the corner of the penthouse enclosure as shown in Figure 8. The two transceivers, being standard production line items, exhibited different IF gain characteristics so a direct comparison of their respective video outputs was not considered relevant. The transceivers were controlled from separate plan position indicator units situated outside the room containing the transceivers, together with the video recorder, A-scope display, antenna positioner control, video interface and the Decca rectifiers necessary to power the transceivers and plan position indicators. The rectifier units are shown in Figure 9 and the video recorder-radar display cluster, in Figure 10. A schematic of the video interface is provided in Figure 11.

2.3 Retro-reflector Installation

The various retro-reflectors employed during the course of the study were installed as required near the base of the 10 metre steel tower shown in Figure 12. A track, complete with three carriages, was attached to the tower so as to permit free and continuous movement of the reflectors in the vertical sense over a range of three metres. A close-up view of the track, showing one of the carriages, is presented in Figure 13. A metric scale was fixed to the side of the track to facilitate accurate positioning of the reflectors in the multipath experiments. Examples of the dihedral and trihedral reflectors used in the project appear in Figures 14 and 15 respectively.

2.4 Antenna Alignment

Given the one and a half degree beamwidth of the antennas used both to illuminate the retro-reflectors and to detect their responses, proper alignment of the antennas was considered crucial to the success of the experiments. The transmit-receive antenna was initially focused on the tower at Dofasco with the aid of a radar transponder. The transponder was modified to receive at 9395 MHz, the operating frequency of the Decca transmitter, and to reply at 9420 MHz, the highest frequency to which the Decca receiver could be tuned. The quarter microsecond pulse emitted by the transponder would ordinarily remain undetected in the clutter originating from the vicinity of the tower, however, by tuning the receiver to 9420 MHz the clutter disappeared leaving the transponder reply clearly visible. The transmit-receive antenna was rotated so as to maximize the transponder response indicated on the A-scope display. The riflescope mount was

then adjusted until the crosshairs coincided with the image of the tower as seen through the scope. Subsequent positioning of the transmit-receive antenna was done without the aid of the radar transponder. The receive only antenna was focused on the tower by peaking the transonder response on the A-scope, as before, then the azimuth indicator on the positioner control was manually reset to zero to "preserve" the location of the tower. Positioning of the receive-only antenna did not prove to be a problem as the gear reduction through the positioner made it virtually immune to the effects of wind loading, unlike the transmit-receive antenna whose orientation had to be monitored constantly.

3. DATA ANALYSIS

3.1 Video Sampling Facility

An RCA ADVISER video recorder and a unique video sampling facility developed at the Communications Research Laboratory (CRL) were used to link the radar installation at CCIW with CRL's Hewlett-Packard HP1000 minicomputer on which all subsequent analysis was performed. A diagram showing the relationship between the various components of the video sampling facility is presented in Figure 16.

The sampling facility is designed to accept video and audio signals supplied by an RCA ADVISER video recorder. Typically, the video signal represents the output of a radar receiver while the audio signal contains bearing information. The video signal is reduced, at a predetermined rate, to a sequence of 8-bit samples which are passed in groups of four via a 38-bit data bus to the main data memory of a Floating Point Systems (FPS) AP-120B array processor (AP). Operation of the 38-bit data bus is controlled by an FPS general programmable input-output processor (GPIOP) which resides in the AP main frame and synchronizes the exchange of information between the interface and the array processor. The AP main data memory consists of 65536 38-bit words and can accommodate a maximum of 262144 8-bit samples as a result of the 4-to-1 multiplexing performed in the interface. Memory utilization can be improved in practice by programming the interface to select samples from a region that is bounded in range and azimuth so as to include only the feature of interest. Once the sampling process is complete, the samples are retrieved from the AP main data memory and stored as a file on the HP1000 disk where they remain until requested by an analysis or graphics program.

In sampling the video recordings obtained during the course of the study a standard procedure was adopted. From a 4.3 km swath in range centered on the tower at Dofasco, 256 samples were taken at a rate of 9 MHz over 1000 consecutive transmissions. The sequence of 256 samples was sufficient to cover the region of interest given the 9 MHz sampling rate which, in turn, was chosen so as to ensure that suitably "smooth" A-scope traces could be produced from the raw data. The number of consecutive transmissions over which samples were taken was constrained by the size of the AP main data memory as noted above, however, 1000 proved adequate for the averaging process used to eliminate the effects of thermal noise.

3.2 Signal Averaging

When an A-scope display is used to view the output of a radar reciver the pulse repetition frequency (PRF) of the transmitter, the persistence of the phosphor on the A-scope cathode ray tube (CRT) and the response of the human eye combine to produce a trace in which the effects of thermal noise are reduced through "averaging". The averaging inherent in the A-scope presentation is not evident in the output of the video sampling facility, an example of which appears in

Figure 17. It is important to remember that the A-scope trace is the average of the receiver output over several thousand consecutive transmissions, whereas, Figure 17 represents the receiver output for a single transmission, often referred to as a "sweep".

It is obvious from Figure 17 that the random fluctuations in the receiver output due to thermal noise tend to mask the response of the retro-reflector, whose position is indicated by an arrow extending upward from the abscissa. In order to facilitate a comparison of the various reflectors, it was necessary to emphasize their response by averaging, in the statistical sense, samples taken from 1000 consecutive sweeps. This technique is frequently used to improve the signal-to-noise ratio in noncoherent radars and produces an estimate of the receiver output in the absence of thermal noise, as illustrated in Figure 18 [7].

3.3 Presentation of the Data

Unless otherwise noted, the results of the experiments are presented in A-scope format and in each case represent the statistical average of 1000 consecutive sweeps. The abscissa corresponds to a 4.3 kilometer swath in range centered on the tower while the ordinate corresponds to the amplitude of the radar receiver output in the absence of thermal noise, expressed as an 8-bit integer lying in the interval (0,255). The position of the tower is indicated by an arrow extending upward from the abscissa. A caption in the upper right hand corner of each plot denotes receiving antenna polarization in the polarization experiments and retro-reflector height in the multipath experiments. Where possible, the results of an experiment have been presented on a single page so that the evolution of the response as a function of polarization or height can be conveniently studied.

4. POLARIZATION EXPERIMENTS

Having selected an environment typical of the St. Lawrence Seaway, its response, when illuminated with a one microsecond, horizontally polarized RF pulse, was studied as a function of polarization by rotating the receiving antenna about an axis coincident with line-of-sight to the tower as shown in Figure 19. The receiver output was recorded with the receiving antenna positioned at 0, 20, 40, 60, 80, 82, 84, 86, 88 and 90 degrees with respect to the horizontal. The results of the experiment are presented in Figure 20.

This procedure was repeated with a trihedral reflector located at a minimum in the vertical interference pattern as shown in Figure 21, and later, with a dihedral reflector in the same position as shown in Figure 22. The results of these experiments are presented in Figures 23 and 24 respectively.

These tests were conducted on a hazy day with little or no wind. As a consequence, the surface of the harbour was essentially smooth with occasional ripples arising from localized breezes. It would have been interesting to repeat the experiments during a period of heavy precipitation, however, this was not attempted for lack of a suitable opportunity.

5. MULTIPATH EXPERIMENTS

In order to study the vertical interference pattern characteristic of multipath propagation a dihedral reflector was moved in the vertical sense between apparent nulls in the pattern as determined from observations of the dihedral response on the A-scope display. The receiver output was recorded as a function of reflector height in 50 millimetre increments over the 1.2 metre interval bounded by the nulls. Figures 25 through 27, respectively, show the dihedral positioned at the lower null, the maximum and the upper null of the particular lobe of the interference pattern investigated during the course of the experiment. The results of the experiment are presented in Figure 28.

This procedure was repeated using a trihedral reflector, and later, using a pair of dihedral reflectors. The dihedral reflectors were separated by one and a half times the distance between the nulls such that when the lower dihedral occupied a null, the upper dihedral occupied a maximum as shown in Figure 29. Vertical movement in the case of the dihedral constellation was limited to 0.6 metres for logistic reasons, hence, the lower element moved between the lowermost null and the lower maximum while the upper element moved between the upper maximum and the uppermost null, the separation of the elements being constant at all times. The results of these experiments are presented in Figures 30 and 31 respectively.

The vertical interference patterns shown in Figure 32 were obtained by plotting receiver output as a function of height at a constant range corresponding to that of the tower. To emphasize the degree of signal fade experienced as a result of multipath propagation, the patterns were normalized with respect to their peak values and plotted separately. Normalized interference patterns for the dihedral reflector, trihedral reflector and dihedral constellation appear in Figures 33 through 35 respectively.

The dihedral and trihedral experiments were conducted on a cloudy day with little or no wind while the dihedral constellation experiment was performed on a sunny day with very light winds. In both instances, the surface of the harbour was smooth with minor, localized disturbances arising from brief gusts of wind. The experiments were to have been repeated on a windy day with substantial wave action, however, suitable conditions did not occur during the course of the study.

6. CONCLUSIONS

(1) The amplitude of the cross polarized return from an environment typical of the St. Lawrence Seaway is less than that of the like polarized return (ref. Figure 20).

(2) The trihedral retro-reflector produces a like polarized return, whereas, the dihedral produces a cross polarized return, when inclined at 45 degrees to the incident polarization (ref. Figures 23 and 24).

(3) The vertically polarized return from a dihedral of modest dimension is easily distinguished from the ambient clutter, while the horizontally polarized return from a trihedral of comparable cross section is not (ref. Figures 23 and 24).

(4) Heavy precipitation tends to increase the level of clutter present in the cross polarized return though not to the same extent as in the like polarized case.

(5) The vertical interference patterns obtained for the individual dihedral and trihedral reflectors are chracteristic of multipath propagation and are indicative of the signal fade experienced by a vessel moving toward a stationary reflector (ref. Figures 33 and 34) [6];

(6) The vertical interference pattern for a simple dihedral constellation does not exhibit the pronounced nulls obtained for a single dihedral (ref. Figures 28 and 31).

(7) Interference from other X-band marine radars in the immediate vicinity proved highly disruptive towards the end of the project, to the extent that data could not be successfully recovered from one of the video tapes due to excessive interference. This problem does not appear to have received appropriate consideration in past studies, particularly in view of its potential for disrupting the operation of an automatic navigation system.

(8) In summary, polarization diversity and space diversity respectively, offer the basis for solutions to the clutter and multipath problems encountered during the PRANS evaluation [1,2,3].

7. RECOMMENDATIONS

(1) In future experiments, a single reflector antenna with a dual polarized feed, mounted on a positioner with a dual channel rotary joint should be substituted for the bistatic arrangement used in the present study. This would ensure improved cross polarization rejection along with constant beamwidths in azimuth and elevation.

The bistatic approach, as implemented for the purpose of these experiments, exhibited minimal cross polarization rejection as indicated in Figure 20. This was further substantiated by observation of the horizontally polarized transponder response as a function of polarization.

Rotation of the receiving antenna to produce the cross polarized return effectively interchanges the azimuth and elevation beam patterns such that the azimuth beamwidth associated with the cross polarized return was considerably larger than that associated with the like polarized return. This tended to discriminate against the cross polarized return by introducing extraneous clutter. A "fair" comparison of like and cross polarized clutter levels should favour the cross polarized case to a greater degree than is evident from Figure 20.

(2) The problem of interference arising from X-band marine radars operating in Hamilton Harbour should be resolved before further experiments are conducted. Altering the frequency of the transceiver would provide an interim solution, however, a practical solution in the operational context would likely require a more elaborate approach such as coded pulse transmission. Both the magnitude and the significance of this problem should not be underestimated.

(3) A retro-reflector with a broad azimuthal response that is capable of producing a cross polarized return should be developed, as the dihedral exhibits a sharp response that would be of little use in an operational environment. The sharpness of the dihedral azimuthal response created difficulties during the experiments, in that, alignment was critical to the magnitude of the return. The anomalous behaviour of certain data appearing in Figure 32 can be attributed to misalignment of the dihedral. The required angular response should be determined on the basis of how the reflectors are likely to be deployed in an actual system.

(4) Retro-directive array technology and in particular, the Van Atta array, should be evaluated as a means of obtaining the desired angular response [8]. Initially, a horizontally polarized array should be studied in an anechoic chamber with the intention of characterizing the angular response and determining both the number of elements and the size of the individual elements necessary to produce an acceptable radar cross section. With these questions resolved, a vertically polarized array should be constructed by inserting polarization shifters in the lengths of waveguide connecting the pairs of elements.

(5) The effects of precipitation on the magnitude of the cross polarized clutter return should be studied and documented for a variety of environments as this will determine the minimum radar cross section of the reflector. There are indications that the magnitude of the cross polarized return will increase with precipitation, however, this needs to be substantiated.

(6) A more comprehensive series of multipath experiments should be undertaken. These should be designed to assess the interaction between surface roughness and the vertical interference pattern; determine the effectiveness of constellations consisting of a large number of small elements; and permit better definition of the interference pattern through extended range and a higher sampling rate in the vertical dimension. If possible, the experiments should be repeated from a vessel approaching the retro-reflector installation since movement of the reflectors in height is not exactly analagous to movement of the radar platform in range. This should serve to establish the fundamental discrepancy between the two approaches.

(7) The accuracy and reliability of the PRANS hardware when coupled to a dual polarized radar should be evaluated. The initial tests should be performed with the antenna dwelling on a single target so as to eliminate the difficulties associated with target acquisition and tracking. The claims made by ACCI with regard to the range accuracy of PRANS appear to contradict a well established body of radar performance theory concerned with parameter estimation [9]. According to the theory, range estimation accuracy is a fundamental property of the radar waveform and the receiver structure and is not merely a function of the precision with propagation delay is measured. The experiment should be designed to resolve the issue as it is of considerable importance in predicting the performance of a navigation system.

(8) Potential users should be contacted and a set of cost-performance tradeoffs prepared that would place limits on system complexity based on economic considerations.

A navigation system constructed to make use of the cross polarized return would likely replace rather than complement an existing radar. For this reason, it would be obliged to offer a conventional horizontally polarized image in addition to the vertically polarized image showing the navigation aids. Conceivably, the images could be superimposed with the vertically polarized image in pseudo-colour, denoting the location of the navigation aids with respect to the coastline.

(9) A study should be made of potential tracking algorithms such as the Kalman filter. A computer simulation should be used to assess the various algorithms on the basis of accuracy, reliability and compactness of course description. An alternative to the present technique, in which two or three targets must be acquired in succession to maintain the correct track, would be desireable.

(10) Methods for displaying course information and position should be investigated as the digital indicators used by ACCI were not well received by potential users [10].

Figure 1 Plan View of Hamilton Harbour

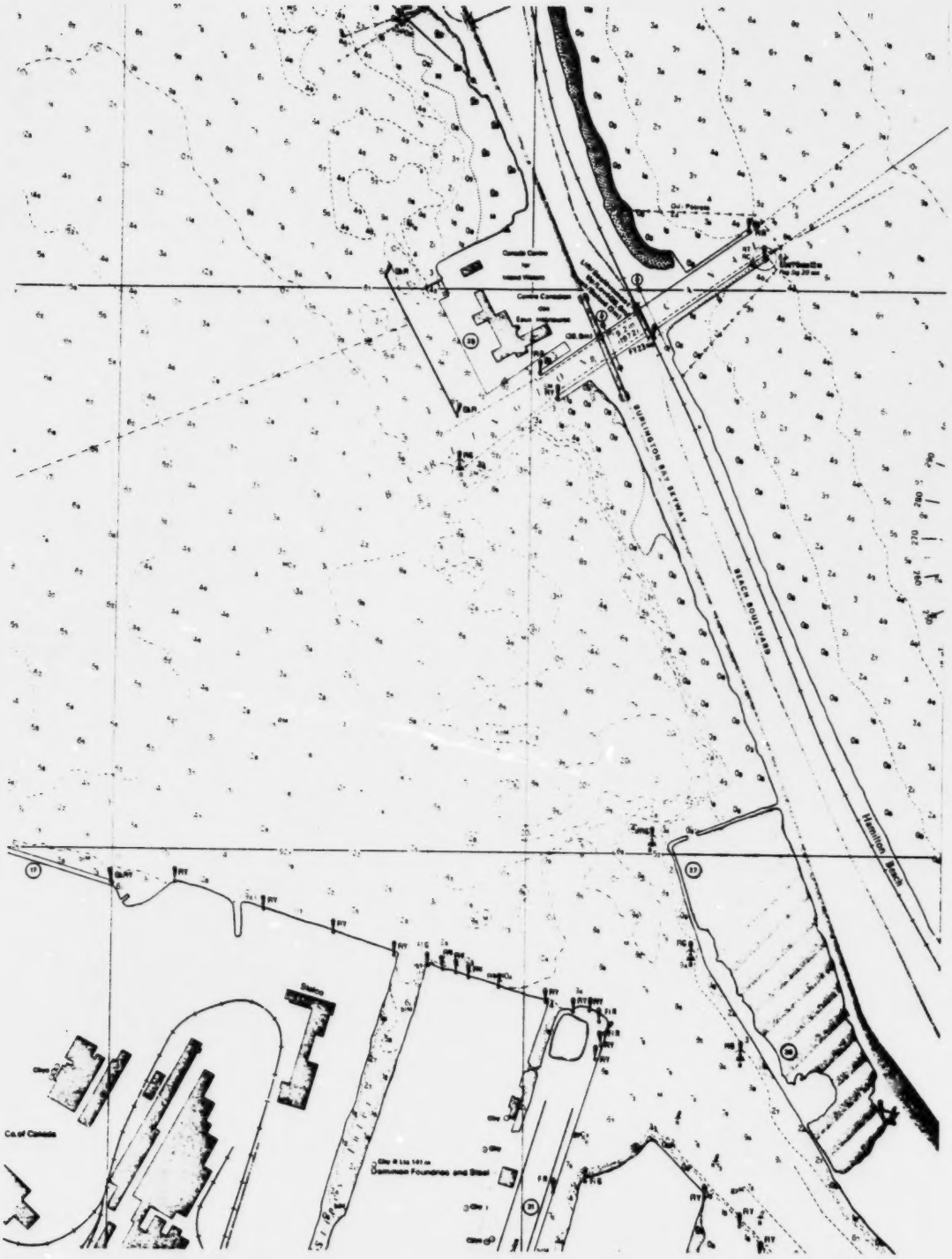


Figure 2 Expanded View of the CCIW-Dofasco Corridor

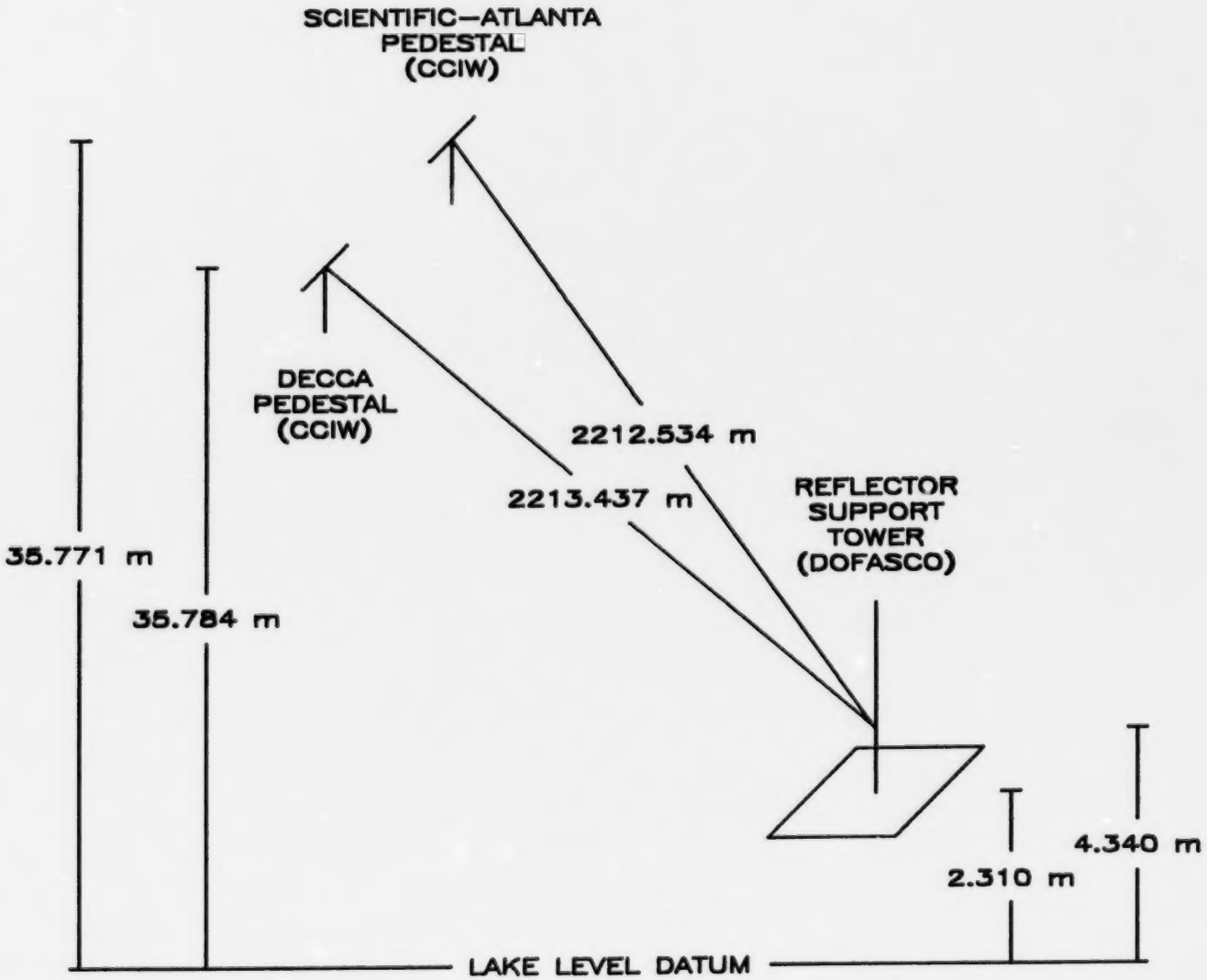


Figure 3 Profile of Test Site (from measurements made by Mike Powell, CHS)

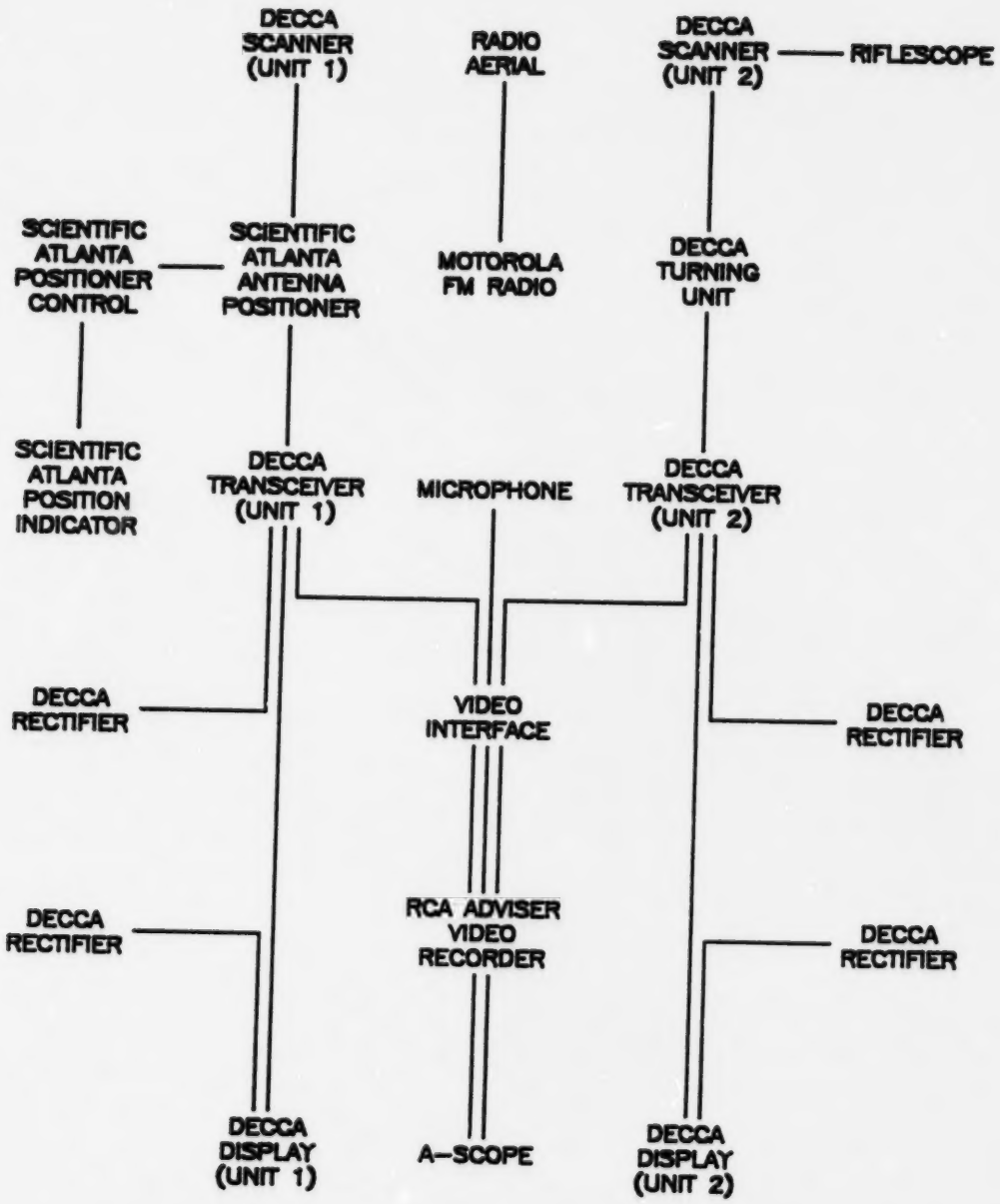


Figure 4 Radar Facility at CCIW

1. Decca Scanner (Unit 1), Type 65148, Class X, SN P.11415

2. Scientific Atlanta Antenna Positioner, Model 5303-1-R1, SN 74

3. Scientific Atlanta Positioner Control, Model 4116-10, SN 260

4. Scientific Atlanta Position Indicator, Model 4422-12, SN 1069
   - Elevation Indicator, Model 4402-5, SN 1390
   - Azimuth Indicator, Model 4401-5, SN 1557

5. Decca Transceiver (Unit 1), Type 65160, Class B, SN P5853

6. Decca Display (Unit 1), Type 65169NA, Class B, SN P3569

7. Radio Aerial, Larsen Kulrod, PO-150

8. Motorola FM Radio, PT300, Model CP33DEN, SN J612BA

9. RCA ADVISER Video Recorder
   - Transport Unit, PN 8376169-501, SN 01
   - Head Panel Assembly, MI591413, SN 3131
   - Electronics Unit, PN 8376170-501, SN 01

10. A-Scope, Tektronix 465 Oscilloscope, SN B176269

11. Decca Scanner (Unit 2), Type 65148, Class X, SN P.07964

12. Riflescope, Bushnell 3X-7X, Custom .22, SN NO. 083326

13. Decca Turning Unit, Type 65216, Class X

14. Decca Transceiver (Unit 2), Type 65160, Class B, SN P5575

15. Decca Display (Unit 2), Type 65169NA, Class B, SN P3847

16. Decca Rectifiers
   - Type 65144CA, Class B, SN P10610
   - Type 65173CA, Class B, SN P3198
   - Type 65144CA, Class B, SN P17526
   - Type 66144CA, Class B, SN P19663

Table 1 Equipment Comprising the Radar Facility at CCIW

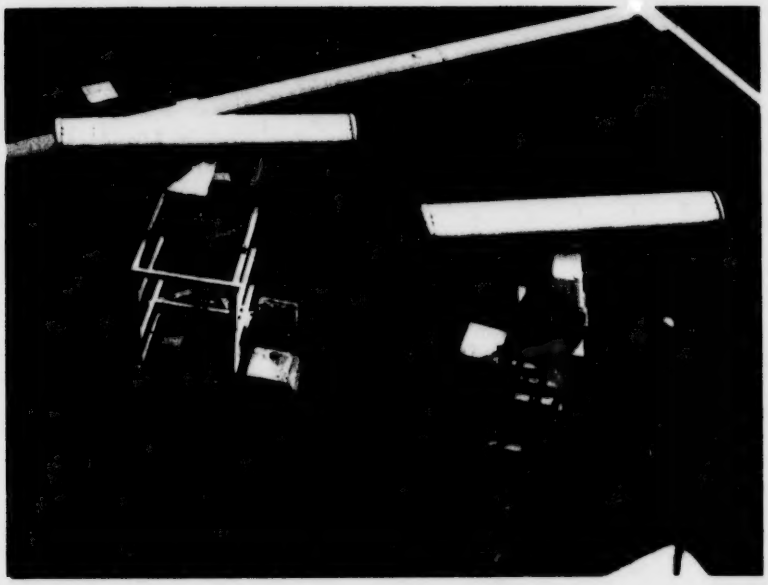


Figure 5 Antenna Pedestals (Top View)

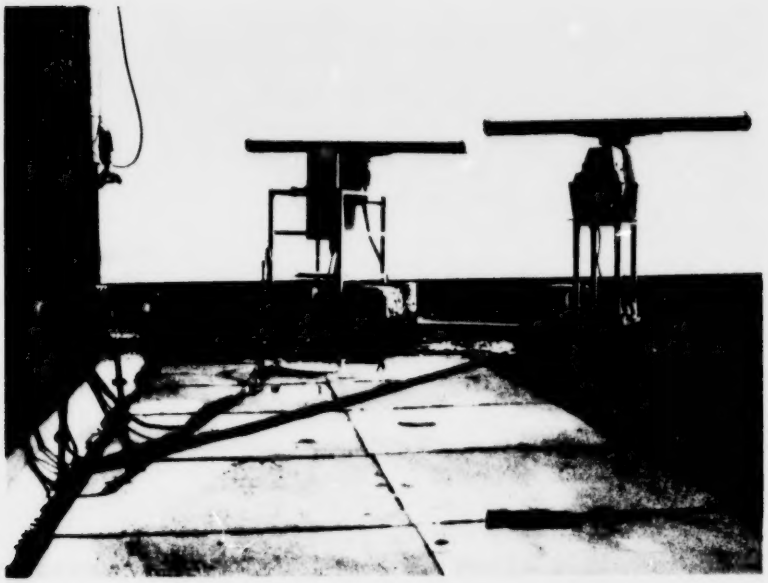


Figure 6 Antenna Pedestals (Rear View)

Figure 7 Riflescope Installed on the Transmit-Receive Scanner

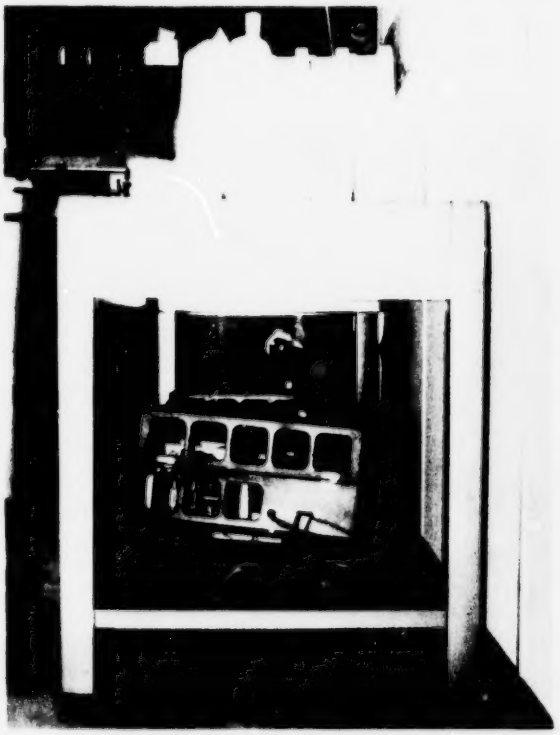


Figure 8 Decca Transceiver Units

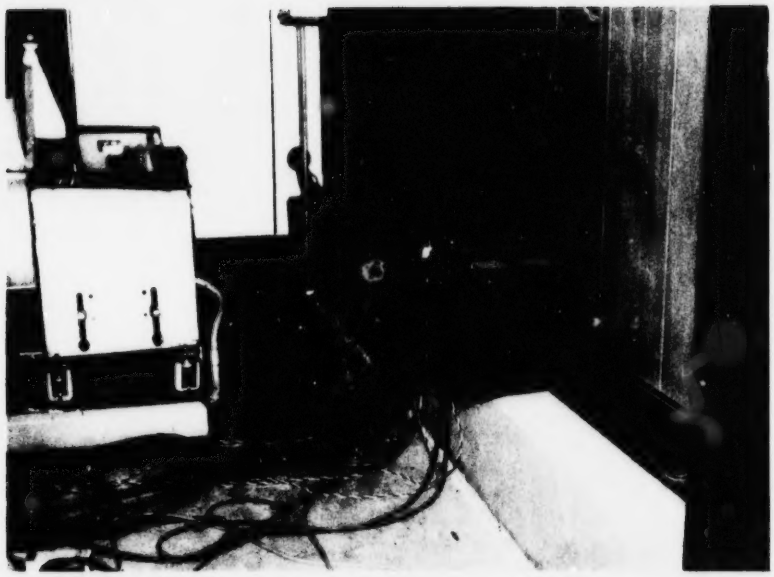


Figure 9 Decca Rectifier Units

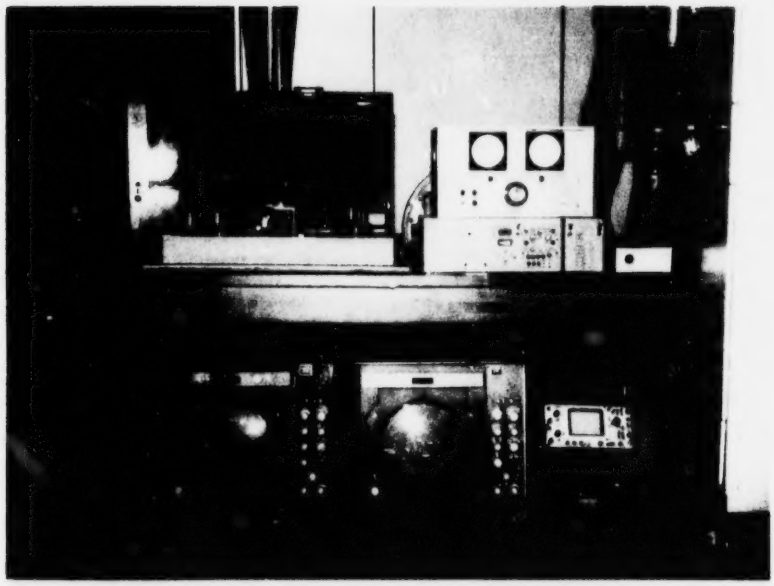


Figure 10 Video Recorder - Radar Display Cluster

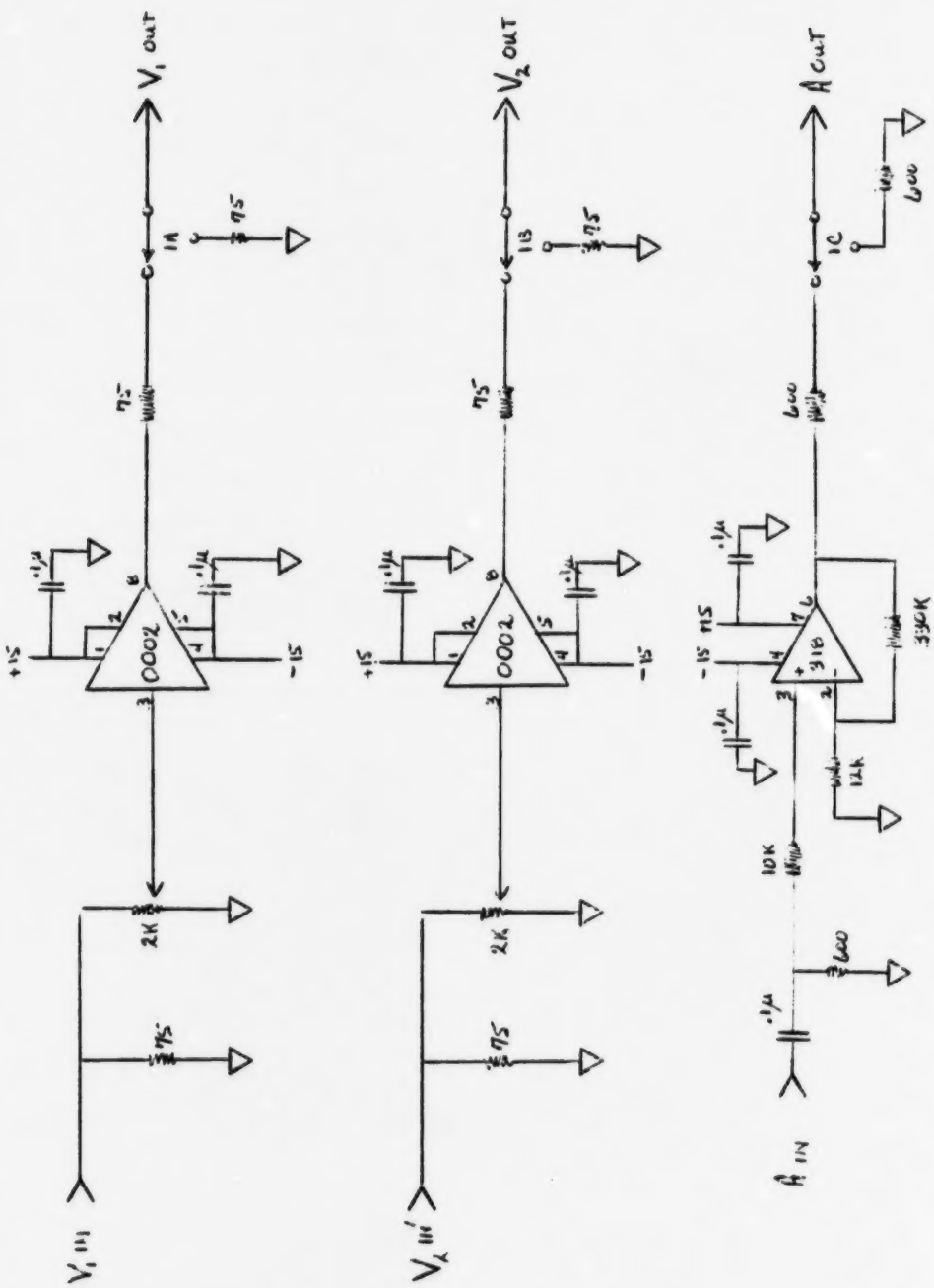


Figure 11 Video Interface Schematic
(Prepared by Jonathan Betz)

Figure 12 Retro-reflector Support Tower at Dofasco

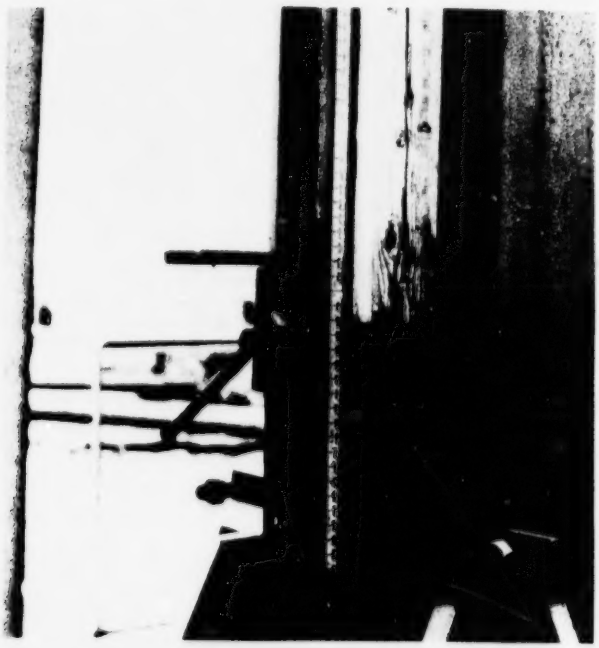


Figure 13 Reflector Mounting Hardware

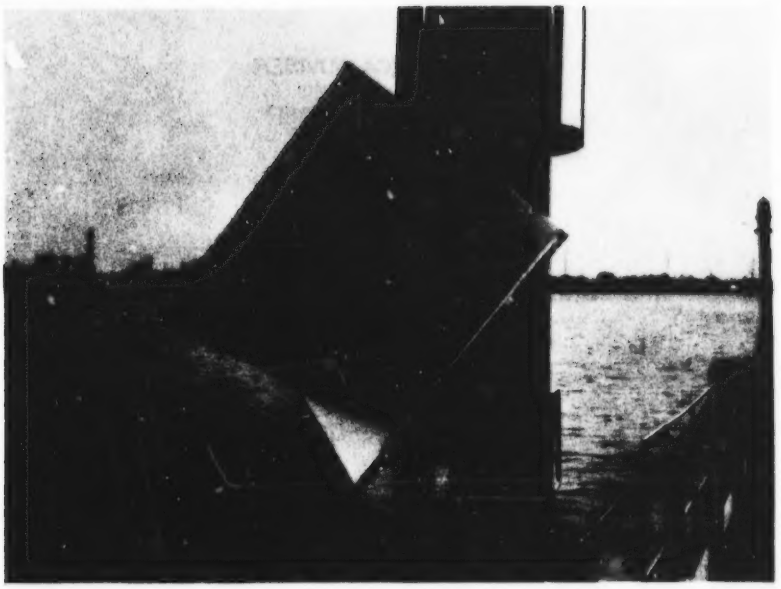


Figure 14 Dihedral Retro-reflector

Figure 15 Trihedral Retro-reflector

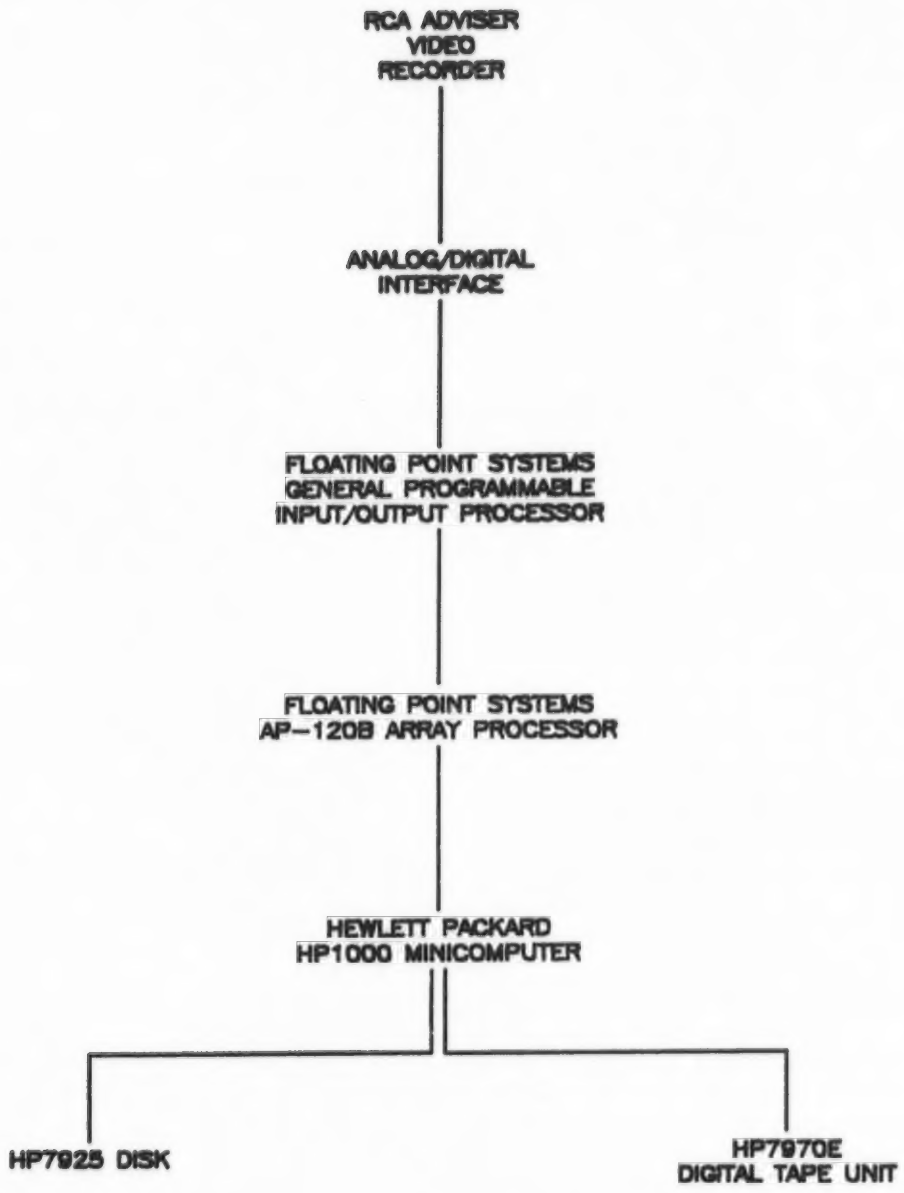


Figure 16 Video Sampling Facility at CRL

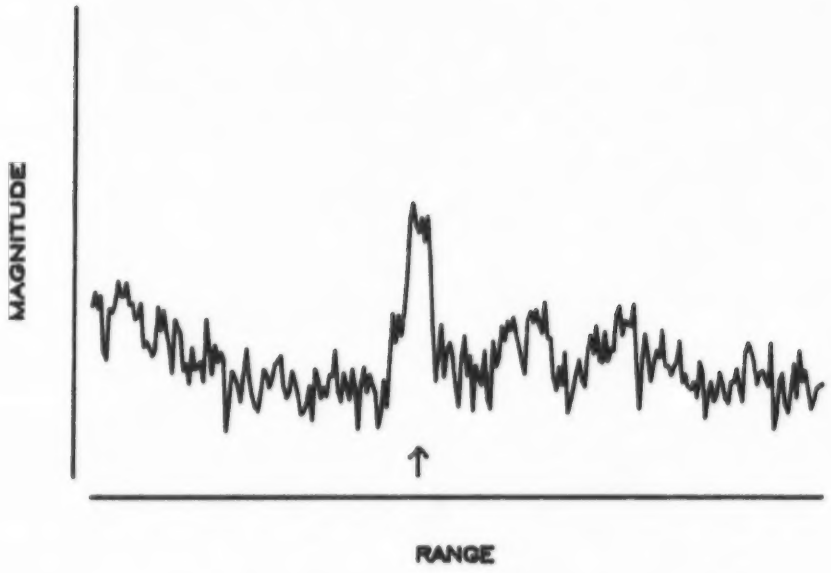


Figure 17 Radar Receiver Output (Unaveraged)

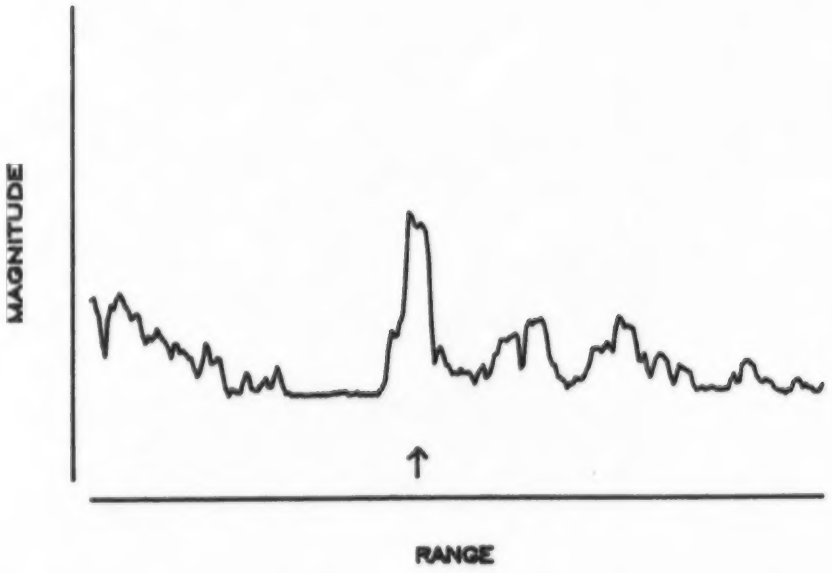
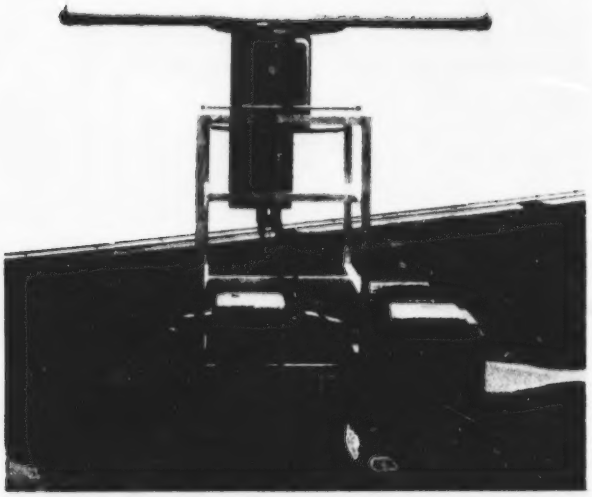
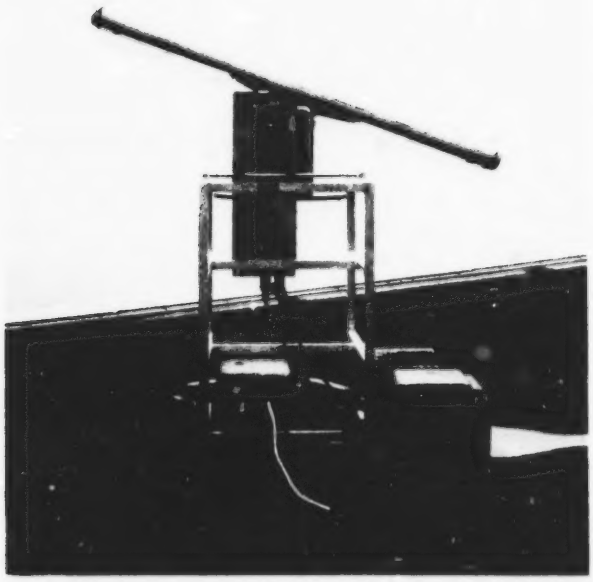


Figure 18 Radar Receiver Output (Averaged)



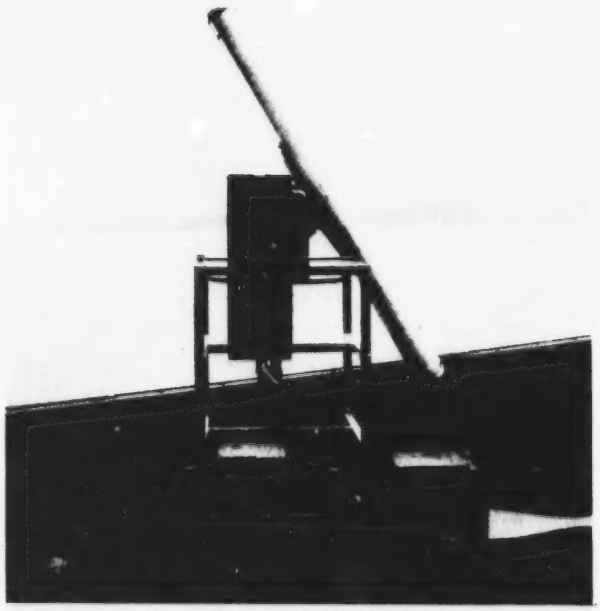
0°



20°

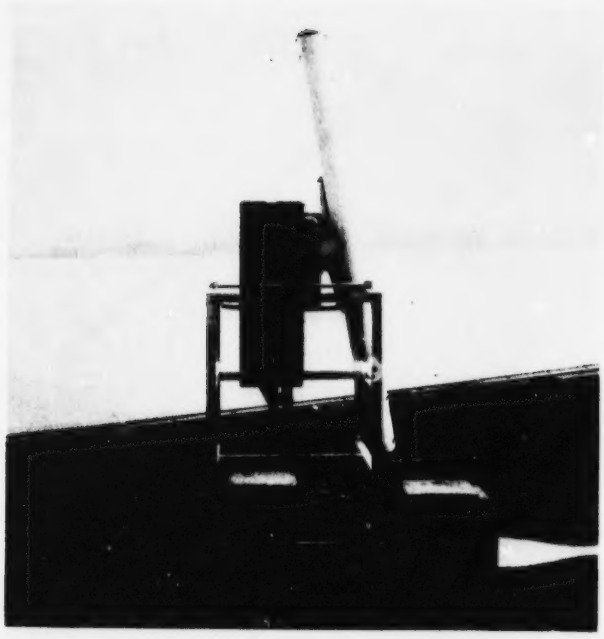
Figure 19 Variation of Receiving Antenna Polarization

40°

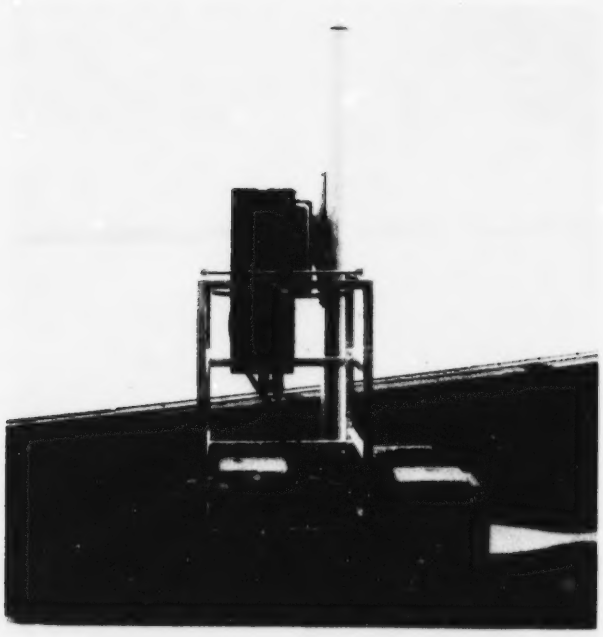


60°

Figure 19 Continued



80°



90°

Figure 19 Continued

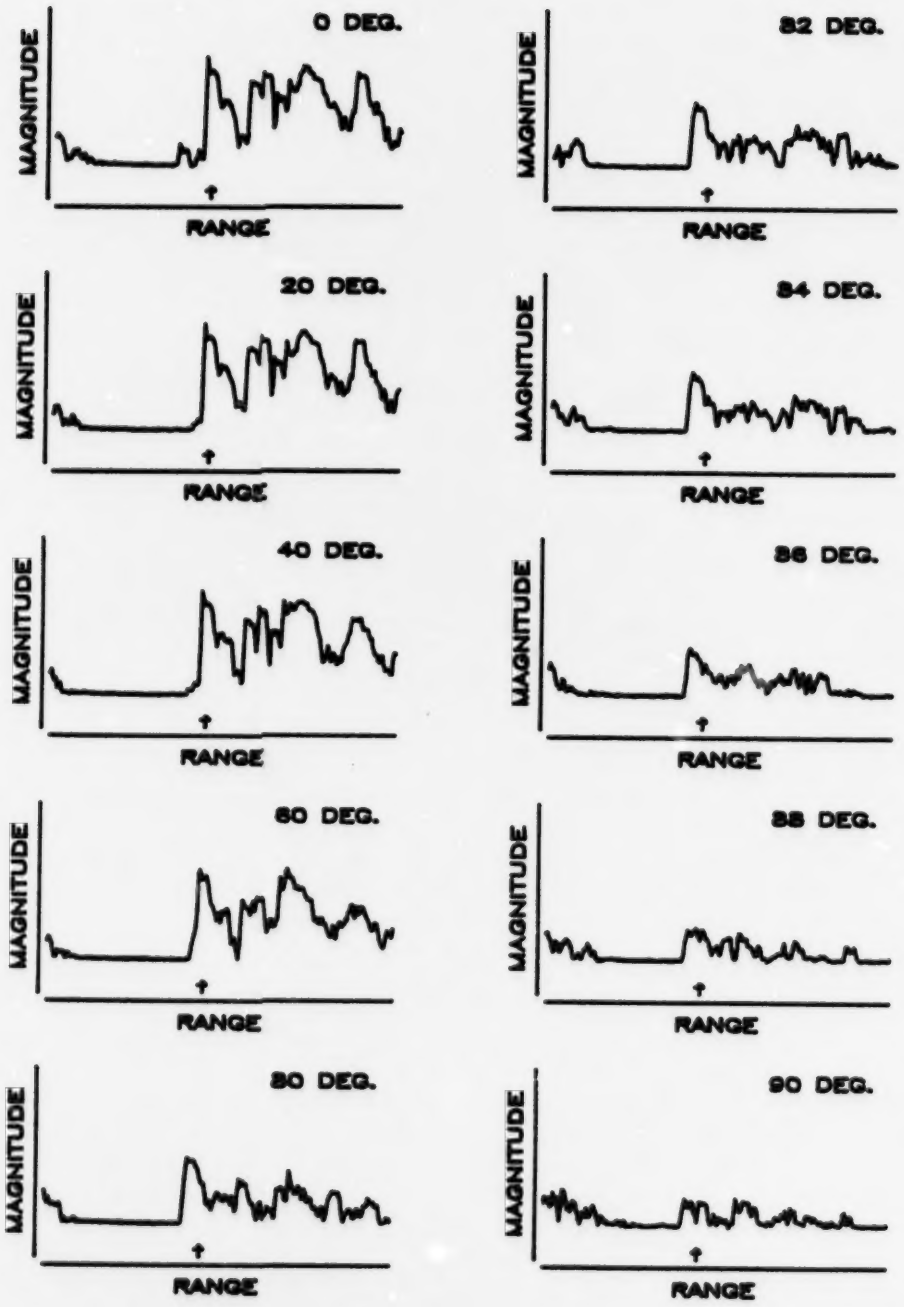


Figure 20 Receiver Output as a Function of Polarization
(No Reflector)

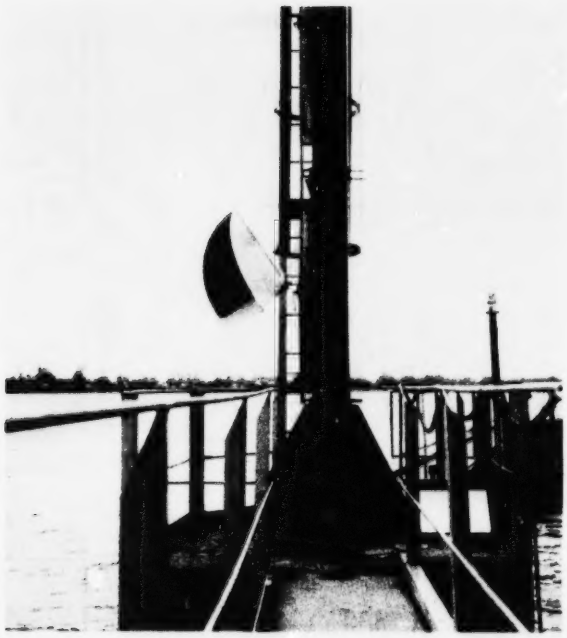


Figure 21 Trihedral Reflector Located at a Maximum in the Vertical Interference Pattern

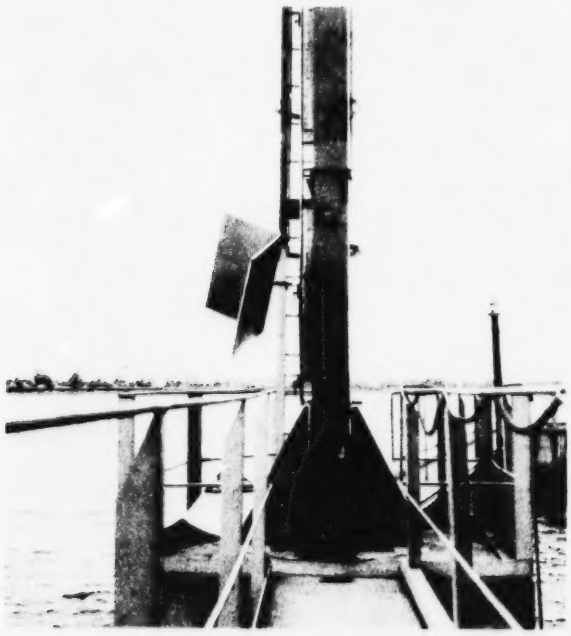


Figure 22 Dihedral Reflector Located at a Maximum in the Vertical Interference Pattern

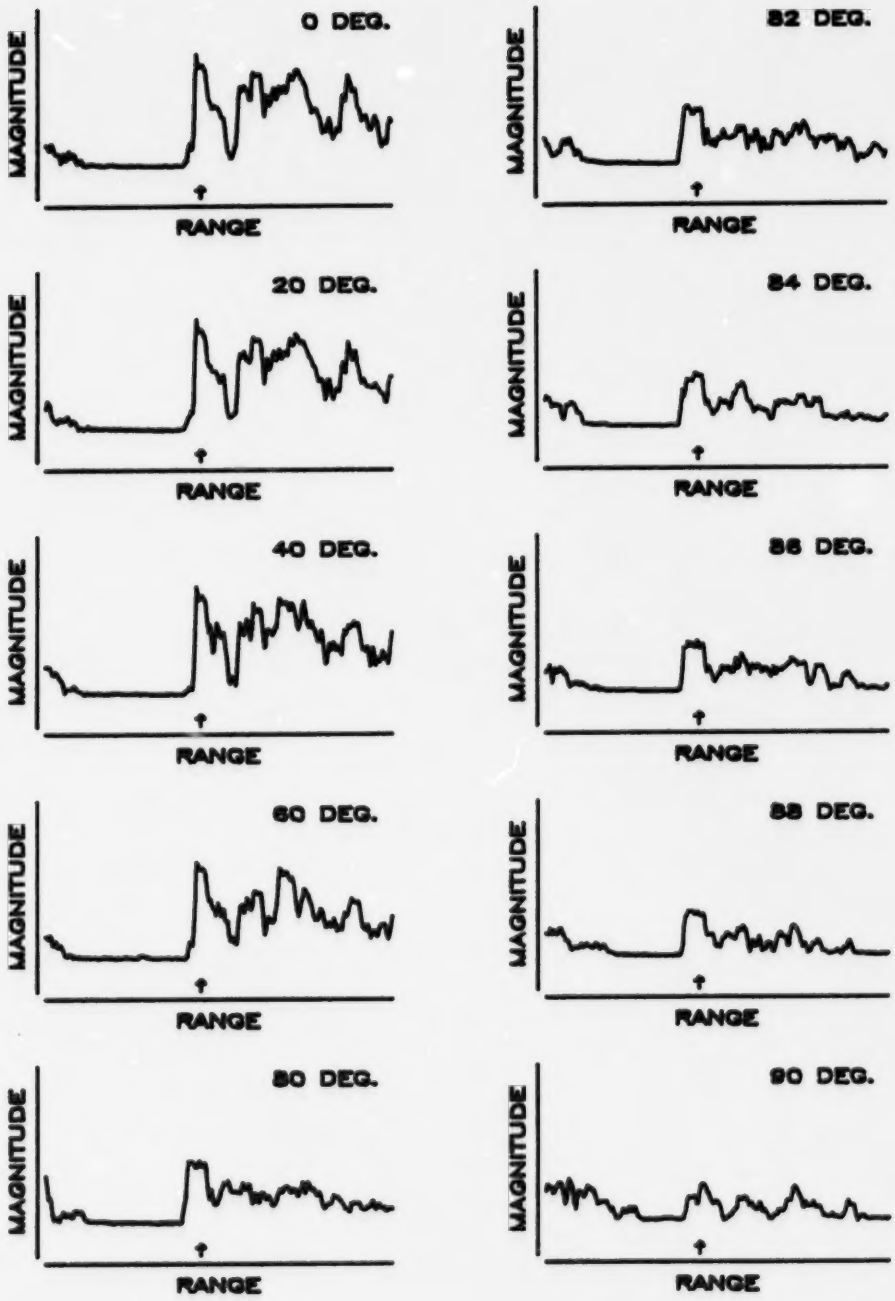


Figure 23 Receiver Output as a Function of Polarization
(Trihedral Reflector)

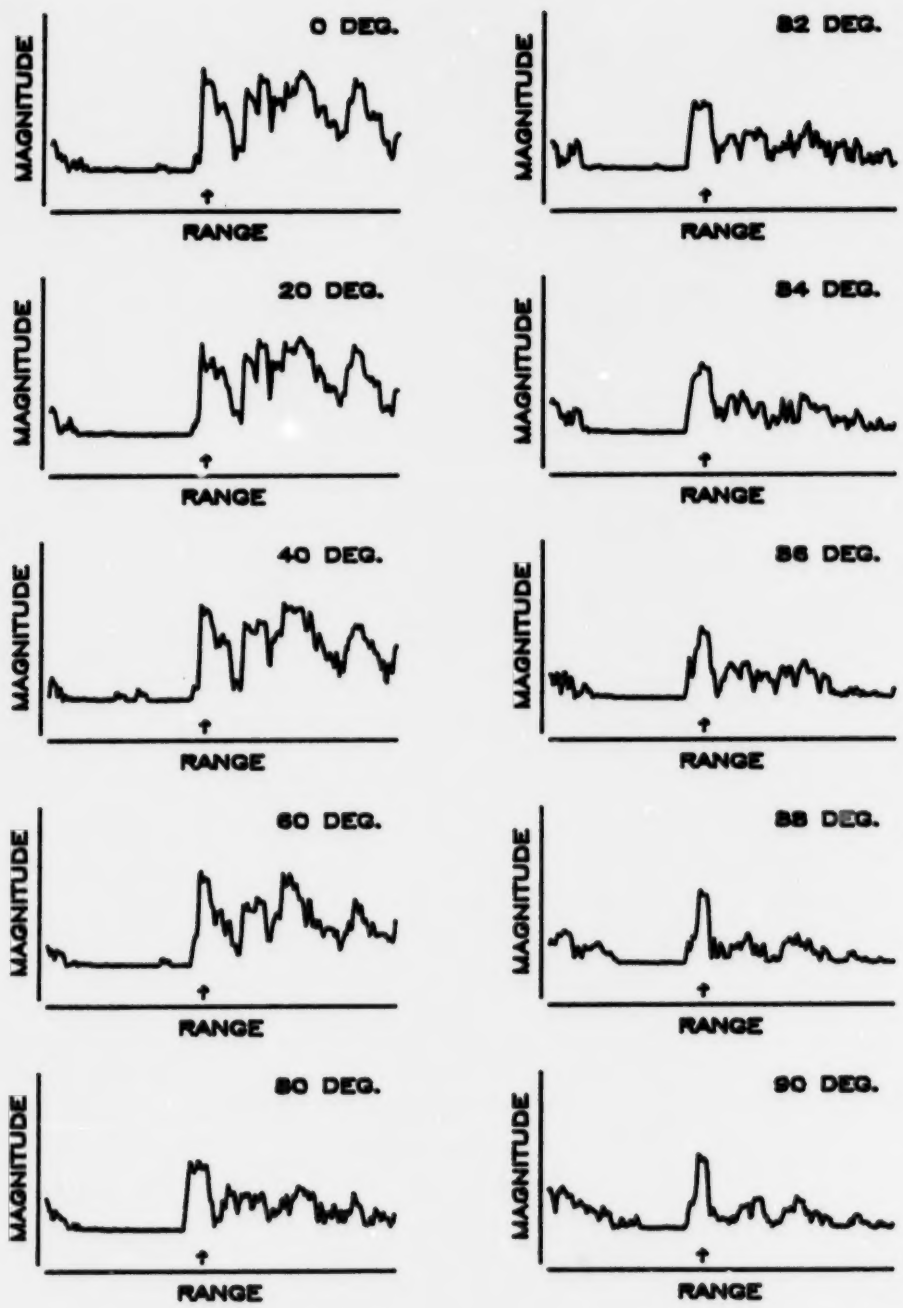


Figure 24 Receiver Output as a Function of Polarization
(Dihedral Reflector)

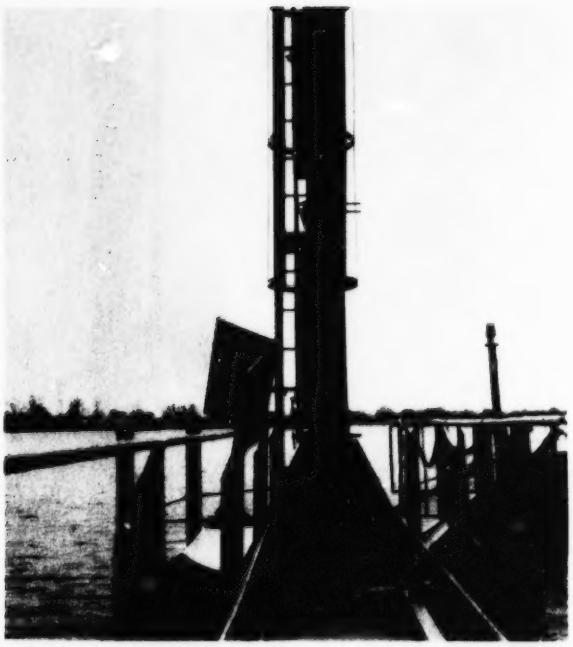


Figure 25 Dihedral Reflector Positioned at the Lower Null of the Vertical Interference Pattern

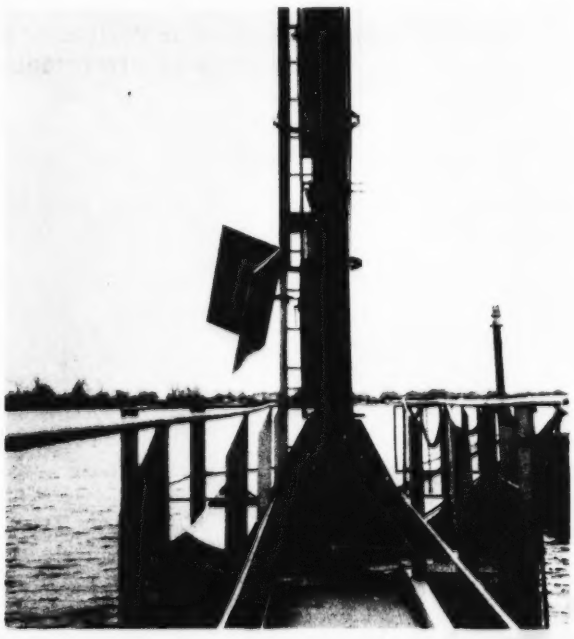


Figure 26 Dihedral Reflector Positioned at a Maximum of the Vertical Interference Pattern

Figure 27 Dihedral Reflector Positioned at the Upper Null of the Vertical Interference Pattern

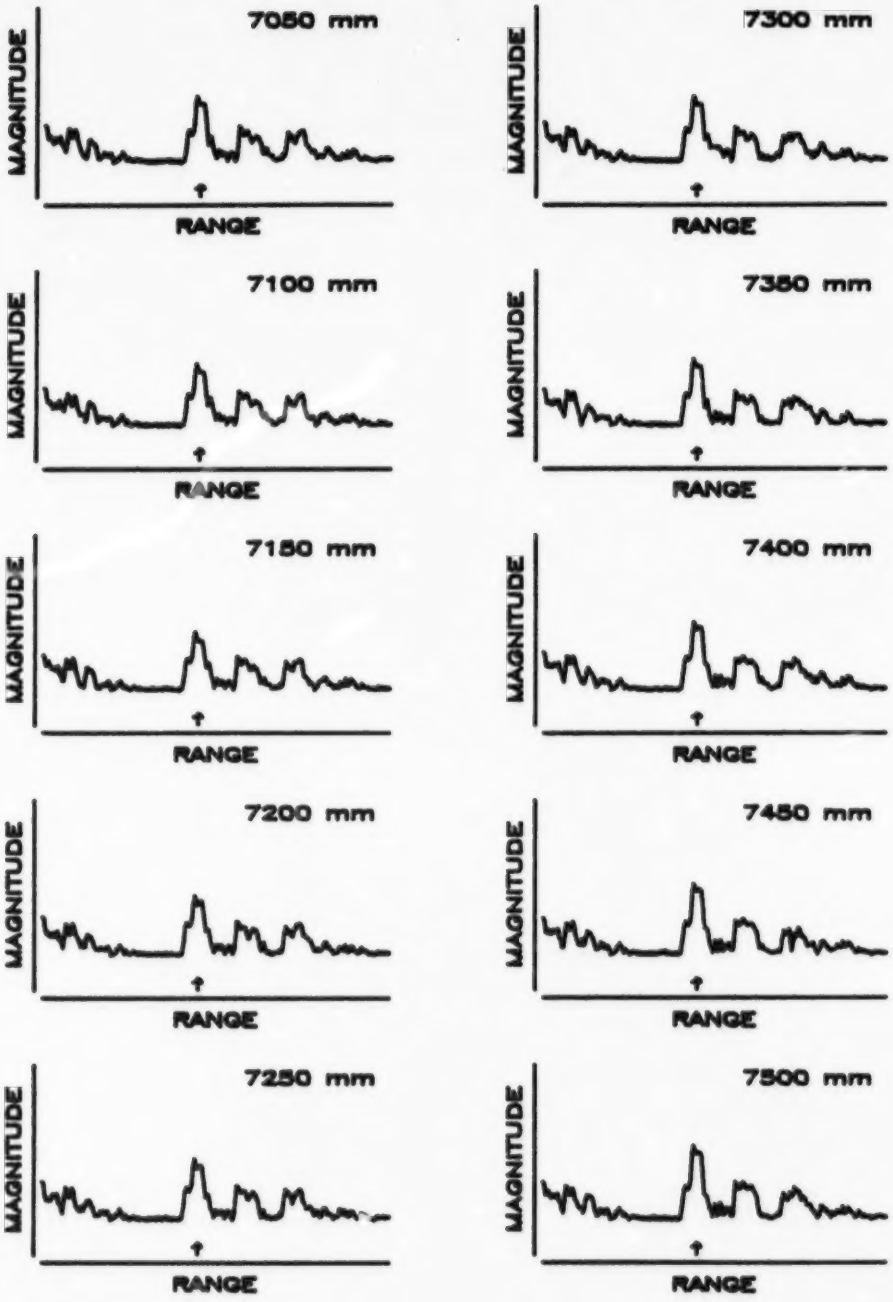


Figure 28 Receiver Output as a Function of Reflector Height (Dihedral Reflector)

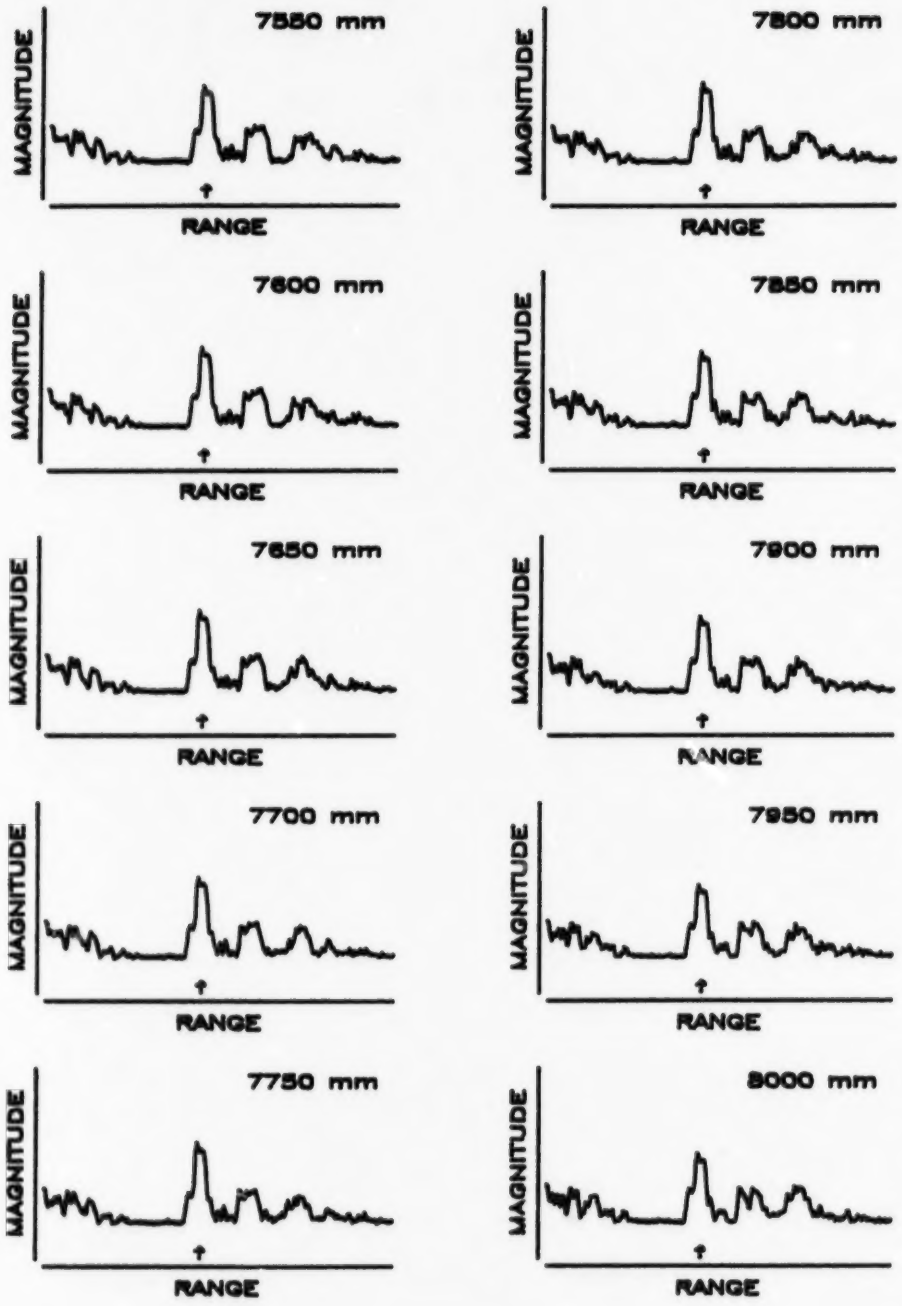


Figure 28 Continued

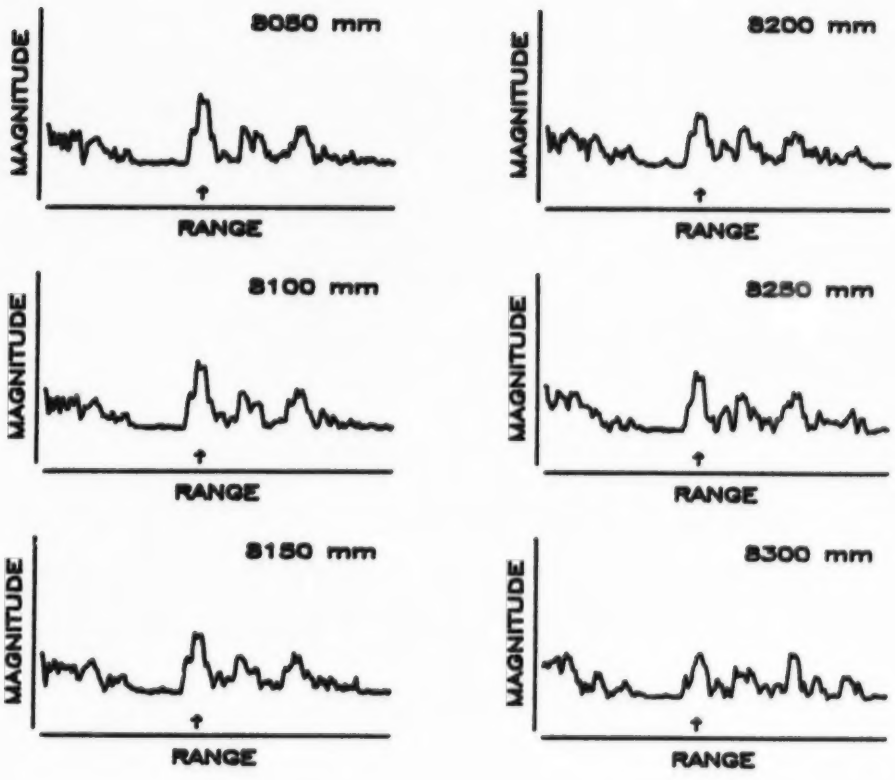


Figure 28 Continued

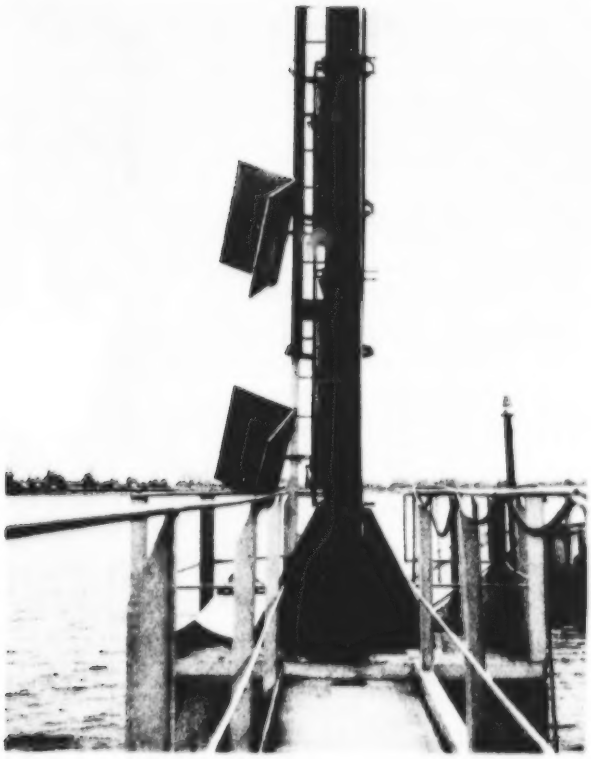


Figure 29 Dihedral Constellation

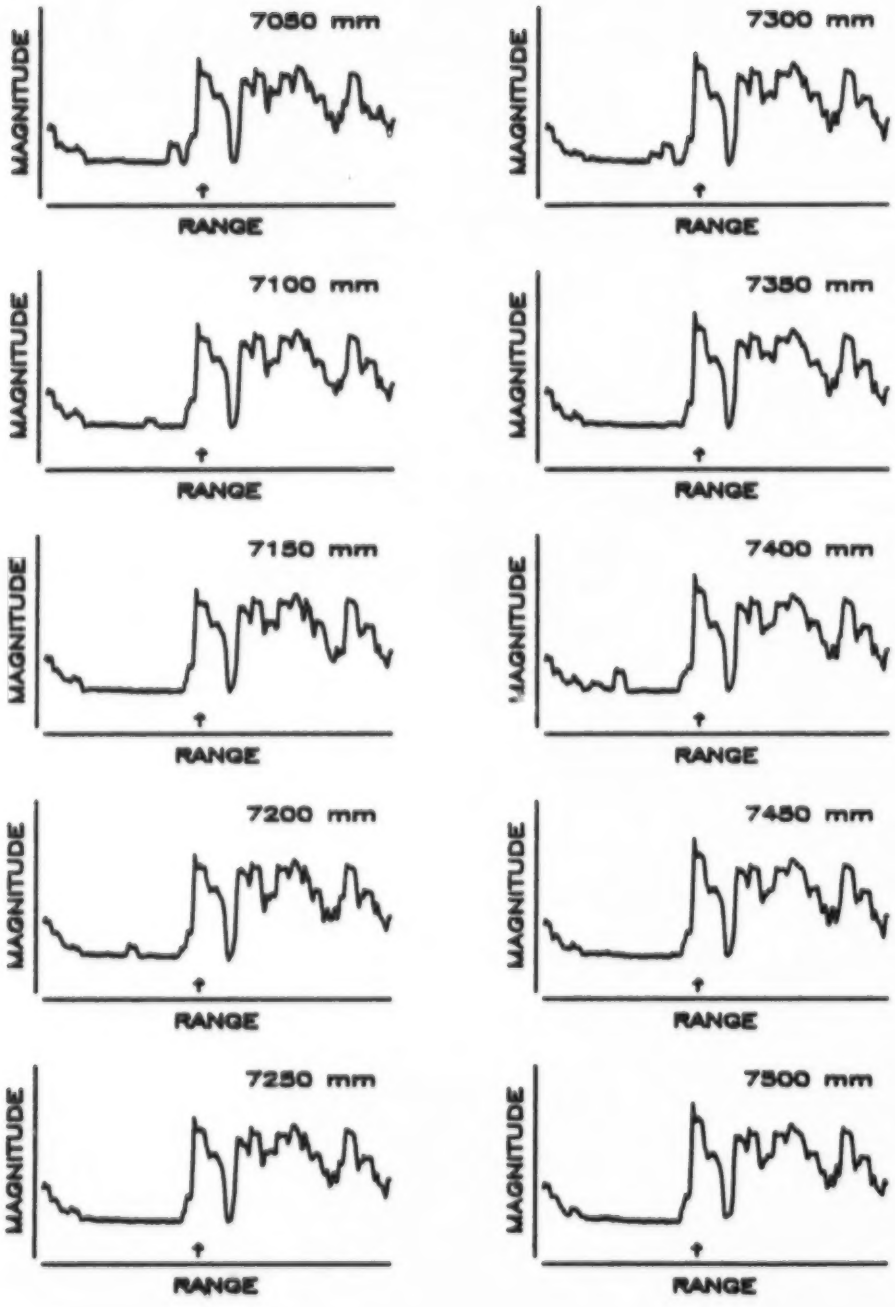


Figure 30 Receiver Output as a Function of Reflector Height (Trihedral Reflector)

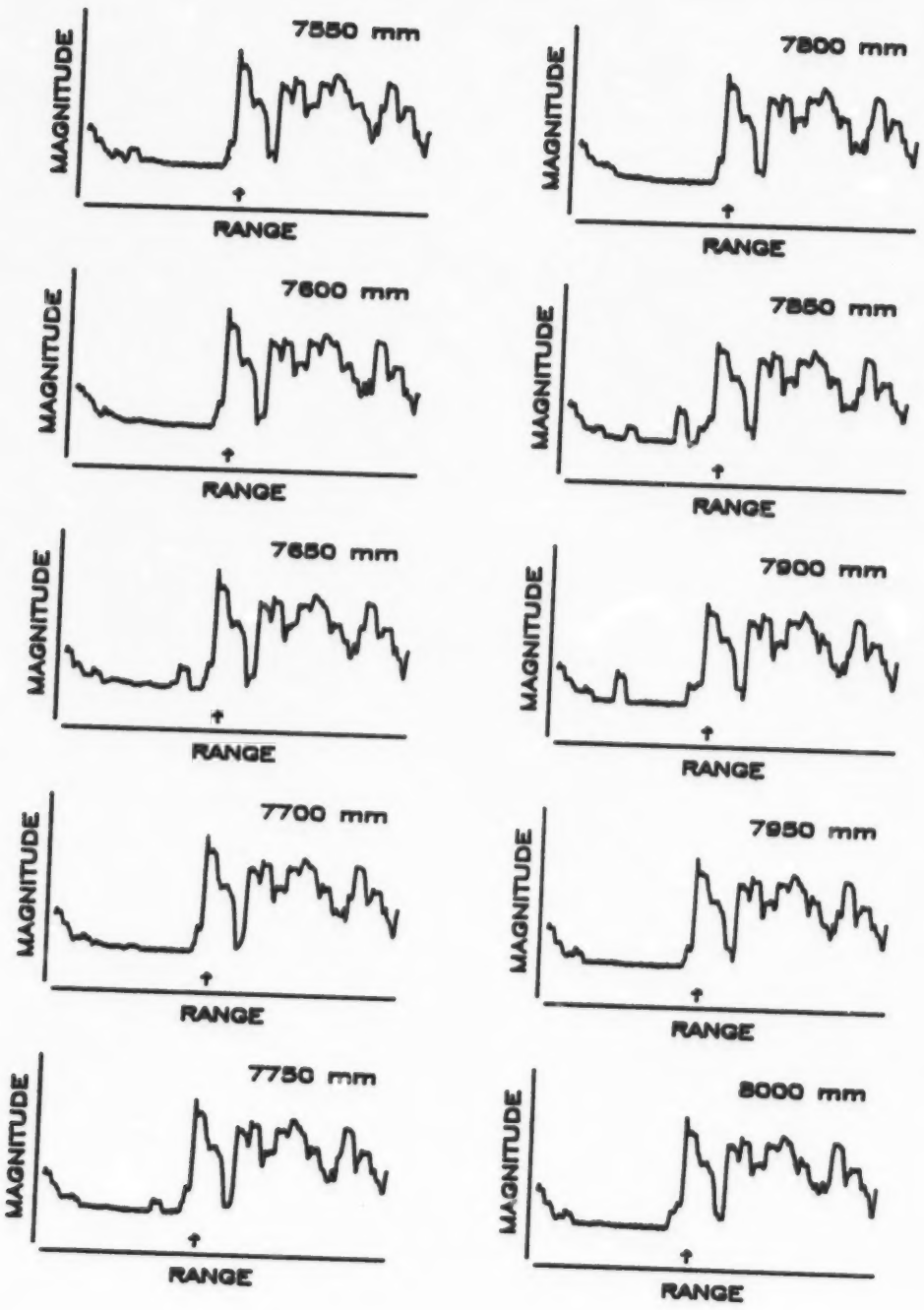


Figure 30 Continued

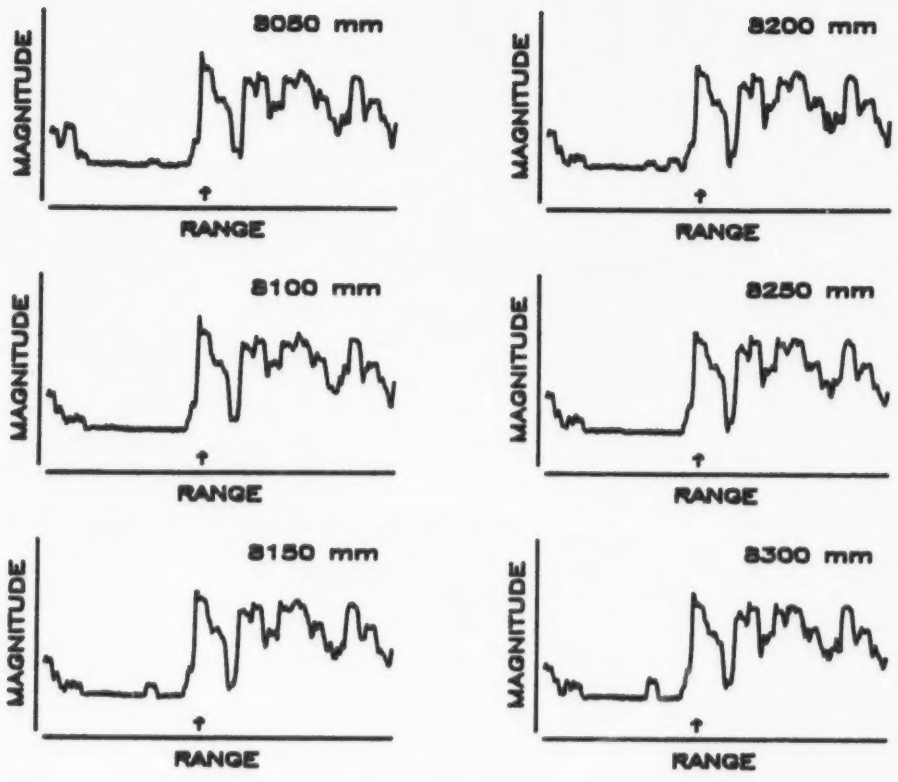


Figure 30 Continued

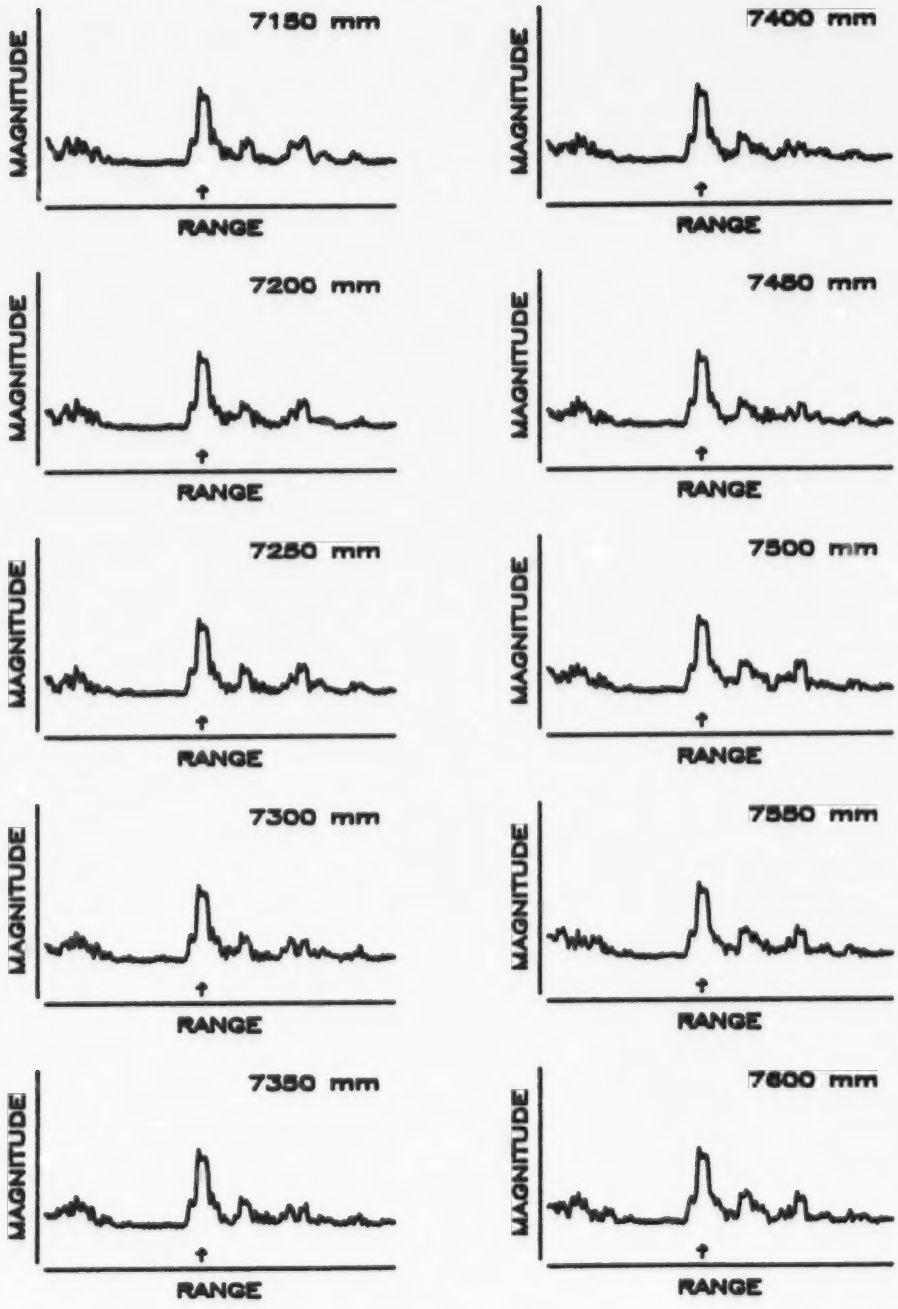


Figure 31 Receiver Output as a Function of Reflector Height (Dihedral Constellation)

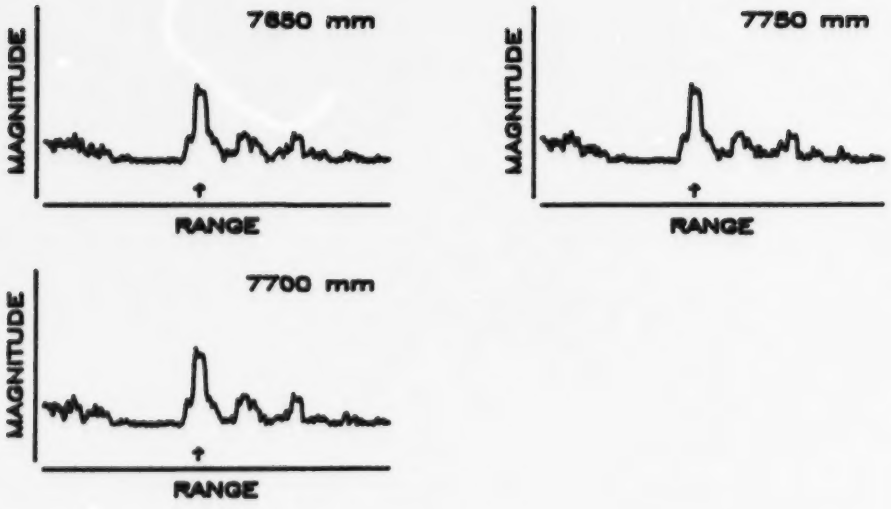


Figure 31 Continued

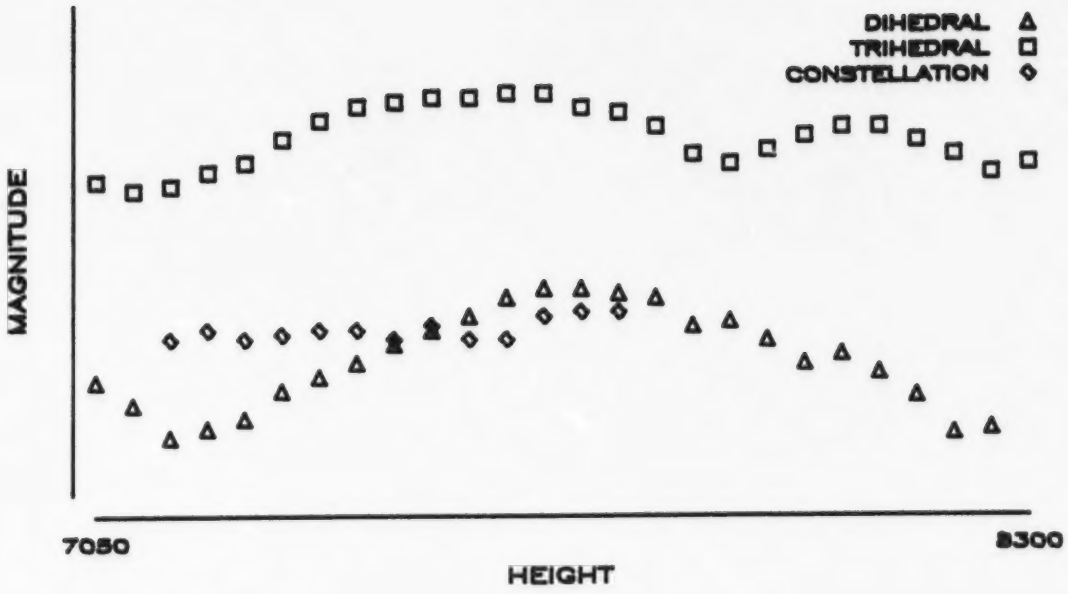


Figure 32 Vertical Interference Patterns for the Dihedral Reflector, Trihedral Reflector and Dihedral Constellation

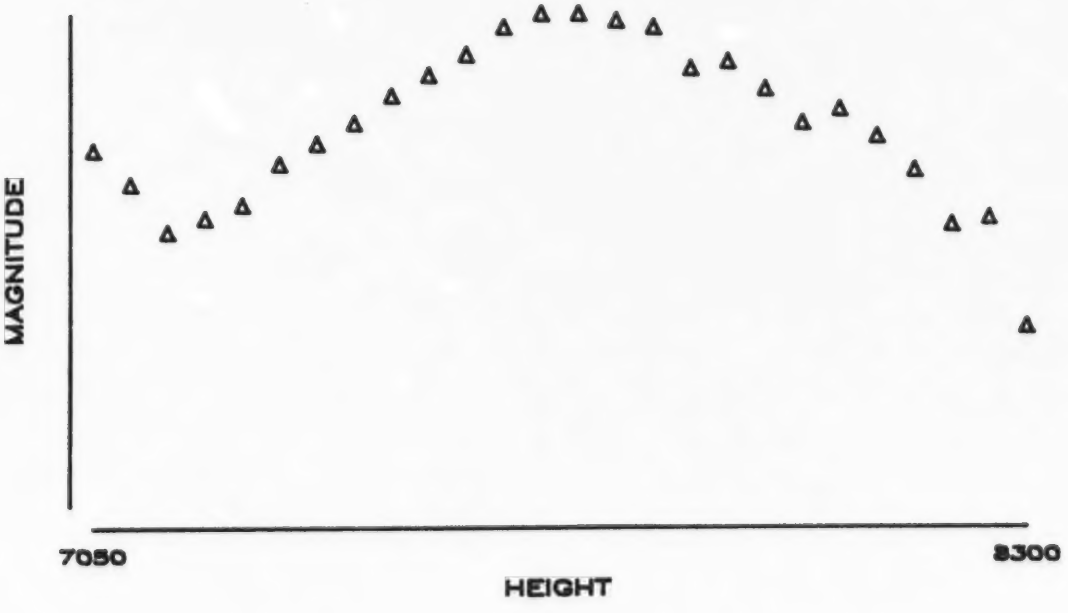


Figure 33 Normalized Vertical Interference Pattern (Dihedral Reflector)

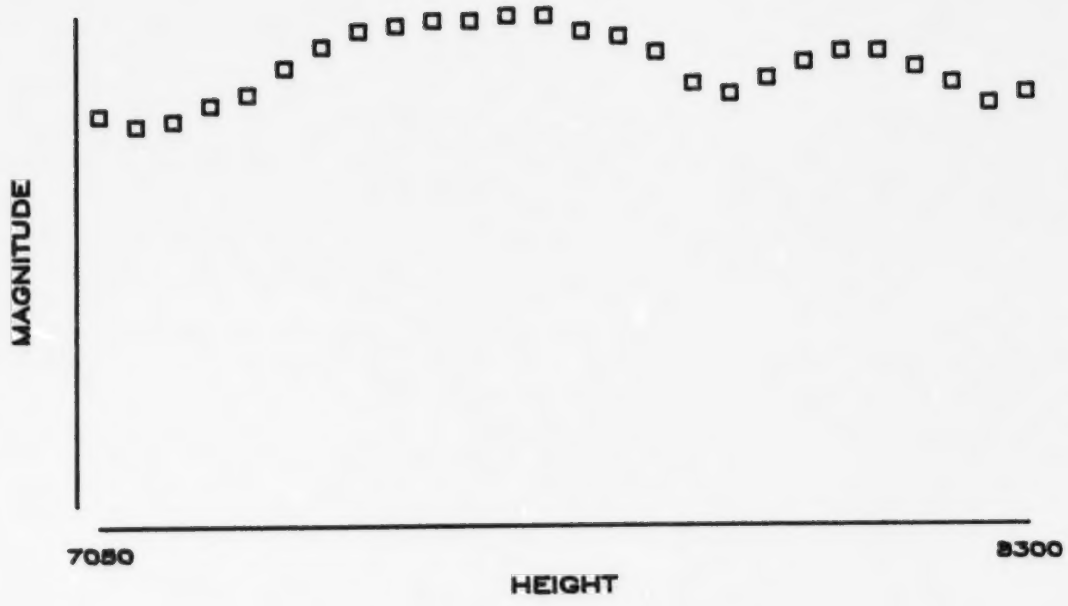


Figure 34 Normalized Vertical Interference Pattern
(Trihedral Reflector)

Figure 35 Normalized Vertical Interference Pattern
(Dihedral Constellation)

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